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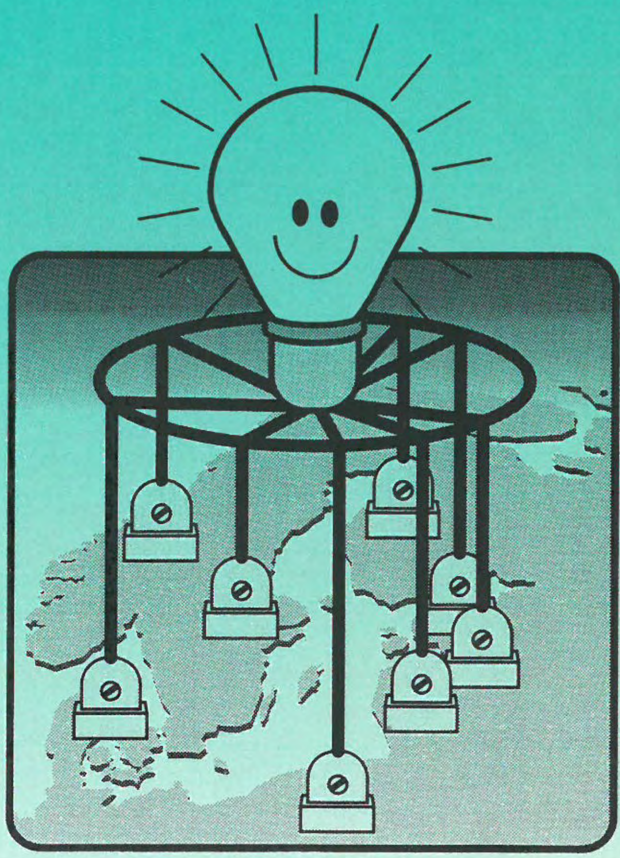
Energy

Perspectives of Regional Coordinated Energy and Environmental Planning



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Perspectives of Regional Coordinated Energy and Environmental Planning

Abstract

This project has focused on analyzing and discussing aspects of sustainability development of the energy systems in the region comprising the Nordic countries, the Baltic republics, and Poland. The sustainability concept is discussed in terms of energy and planning activities that could be coordinated throughout the region.

A database including relevant national official energy statistics was developed. It was used as a basis for developing various scenarios representing each country's expectations of its future energy use, the related impacts of the emissions of carbon dioxide, nitrogen, and sulphur. The energy systems were analyzed and compared in terms of these parameters. The analyses were then used as a basis for discussing problems of assessing the sustainable development of an eight-country region when the concept is applied in practice. The study shows that the Nordic/Baltic region can benefit from engaging in a coordinated planning activity where efforts are focused on the regulation of energy systems in those countries which import the environment most severely. The benefits that accrue will be in the form of improvements in the environment and savings in the economy. A single country's initiatives are not insufficient to secure a sustainable development, however.

Preface

The present report summarizes the third part of the project entitled "Energy and Environmental Planning in the Nordic Countries". The first part described modelling tools and methods used in the planning activities of the Nordic countries. The second part investigated how criteria for sustainable development of the energy system could be translated into goals for energy and environmental tasks in the Nordic countries. These two parts are described in the publications made by Halsnæs (1989), Halsnæs (1990), Halsnæs and Mackenzie (1990) and must be viewed in connection with this report.

The overall purpose of the present report has been to analyze how the concept of sustainable development of the energy system can be made operational for a region comprizing the Nordic countries, the Baltic states, and Poland. In practice, the analysis has focused on environmental benefits of carrying out a coordinated effort throughout the region using goals of diminishing impacts from energy use and production as basis.

The work was divided into three major activities: First, a database was developed including official national statistics, energy parameters, and environmental indicators for evaluating the effects of all energy activities. Next, the energy system of each country in the region was analyzed in terms of its environmental impacts. Finally, the ways in which the assessments of sustainable development of the energy systems can be carried out in practice are discussed, taking the countries of the region as examples. In this connection the coordination of planning activities is also discussed.

The collection of data material, e.g. the national projections for future energy use, has been carried out mostly in 1990 and 1991. There may be countries which have made newer and more updated projections. However, it is the viewpoint of the authors that it is not the individual specific values of the scenarios which are important. The focus should rather be put more on methodological discussions and approaches.

The project has been financed by the Nordic Council of Ministers. The work was carried out by Kirsten Halsnæs and Lene Sørensen, the Energy Systems Group, Risø National Laboratory, Roskilde, Denmark.

Roskilde, 28 October 1993

Kirsten Halsnæs   Lene Sørensen

Contents

1 Introduction

Sustainable development has in the past few years been a phrase often used in all areas where of one kind or another development is sought after or expected. This report attempts to discuss the concept within a limited context, namely, sustainable development of energy systems in a geographical region comprising several countries. The meaning of this is that future developments of an energy system must be carried out by making overall assessments of the effects of energy use and production on the environment and national economies (chapter 5 includes a detailed definition of the concept of sustainable development of the energy system).

In general, the sustainable development concept is far from applicable in practice. There is a lack of consensus on how the concept should be defined, and in the literature many discussions can be found on how to make the concept operational.

This report seeks to analyze how the concept of sustainable development of the energy system can be put into operation for a larger geographical region. Operationalizing the concept implies a holistic view on the impacts of energy consumption and use. This means that environmental problems facing not only one individual country but a larger region and in fact the whole world must be considered. Furthermore, it is important to realize that the concept of sustainable development would hardly have relevance if it were not applied to larger geographical regions at the same time. The most serious environmental problems facing the world at present are transboundary, i.e. regional or global. As a consequence, the project widened the range of countries to include, apart from the Nordic countries, the three Baltic states and Poland as well. This area is considered a region where some sort of cooperation can fruitfully take place in order that the region as a whole develops within a framework of sustainable energy system development. Taken as a whole it is expected that the region will benefit from this cooperation in terms of an increased efficiency of the various energy systems as well as lowered environmental impacts.

The initial scope and approach of the analysis is described in chapter 2. Three environmental problem areas associated with the sustainable development concept are identified as being of decisive importance in planning energy and environmental acitivities. These problems are depletion of exhaustable resources, acidification of the ecosystems, and global climate changes. Three indicators were selected to represent measures for sustainable development. These were the starting points for describing and analyzing the energy systems and pollution sources of the countries of the region. A database was developed that included national official statistics of the countries and parameters defining various scenarios for future use of energy. The indicator values were incorporated into the database to be used as a basis for scenario analyses.

Chapters 3 and 4 describe, respectively, the use of energy and environmental effects, namely carbon dioxide emissions and level of acidification in the countries.

These descriptions then form the basis for a discussion on how the concept of sustainable development can be put into operational terms, the subject of chapter 5. How this can be done is discussed and some suggestions are made as to how to put this in practice. Finally, the benefits of performing an integrated and cooperative effort in the whole region is discussed in respect to the indicators of sustainable development.

The conclusions are presented in chapter 6.

2 Approach and scope

This project has focused on analyzing and discussing different strategies for sustainable development of the eight-country Baltic/Nordic region. Sustainable development has not as yet been defined in operational terms. It is, therefore, necessary to specify the interpretation and selections of this project.

2.1 System setup and problem definition

The overall purpose of the project was to carry out an integrated energy and environmental analysis of a large region comprising by the Nordic and Baltic areas. The project was carried out in order to investigate the environmental impacts resulting from the structural differences between the various energy systems, and the natural resources ocurring within the region, and to discuss the benefits of energy/environmental cooperation among the countries.

Geographically, the analysis considered the four Nordic countries Norway, Sweden, Finland and Denmark, the Baltic states Estonia, Latvia and Lithuania, and Poland. The main justification for this geographical boundary is that these countries may be seen as forming an entity where coordinated energy and environmental planning could be carried out, and where international transfer of technical and economic resources could take place in order to fulfil specific environmental goals in a cost-effective way.

Energy and environmental planning in the region was assumed to relate to the following parameters:

- gaseous emissions like SO_2 and NO_x (referred to as acid emissions) resulting in acidification of the environment,
- CO_2 emissions resulting in global climatic changes, and
- use of fossil fuel equivalents resulting in depletion of exhaustable resources.

In spite of the Nordic relations of Iceland the present analysis does not include the environmental impacts of the Icelandic energy system. The reason for that system boundary is twofold. Iceland has very low acid emissions and there is no significant relationship between acid emissions in Iceland and deposition in other Nordic countries or in the Baltic area. Furthermore, the energy system of Iceland is dominated by hydro power produced electricity which neither has a CO_2 emission or can be said to be a possible substitute for energy produced by fossil fuels in other countries.

These parameters shall be seen together as indicators of the sustainability[1] of the energy system. Here short-term goals for reducing acidic emissions are represented as well as long-term goals relating to the climate effect and preservation arguments concerning the use of exhaustible resources. Arguments for selecting the parameters above as specific indicators of sustainable development of the energy system are given in section 2.2. Additionally, the concept and selections of this project are discussed in broader terms in chapter 5.

In practice, the analysis was performed through the construction and comparison of scenarios. A set of scenarios were developed on the basis of official national energy plans and statistics of the eight countries involved. Figure 2.1 illustrates the analytical method for the analysis.

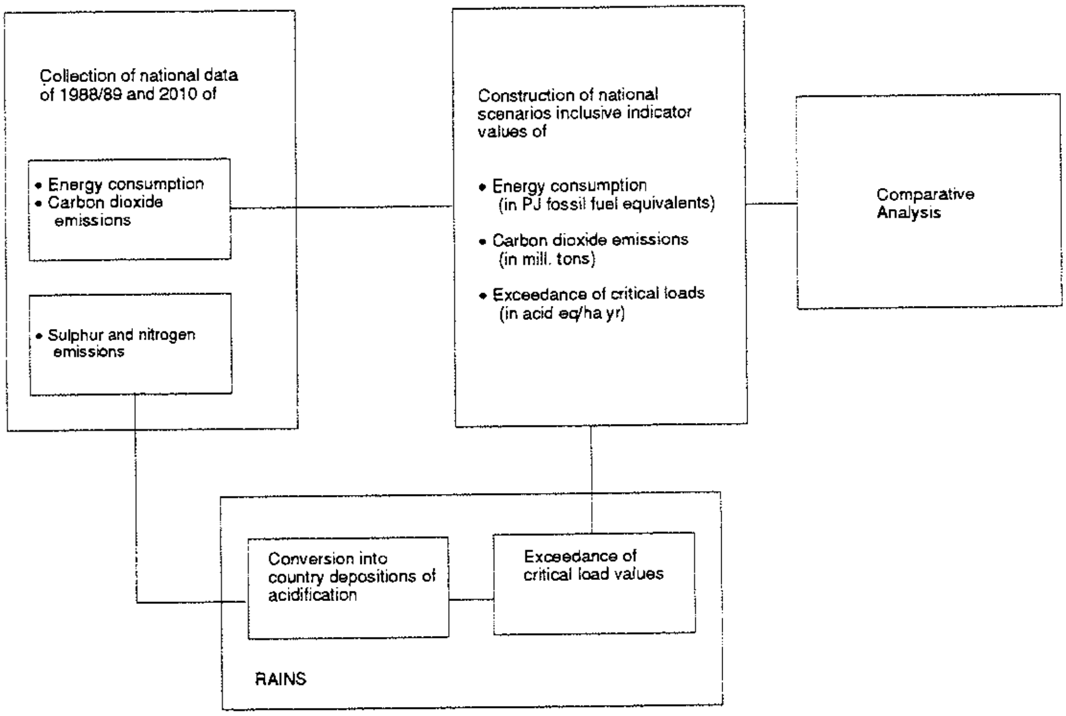

Figure 2.1 Analytical method of the analysis.

Initially, an energy database was developed containing the energy related data for each country for the years 1988/89 and 2010. The database mainly includes data of each country's

- gross energy consumption split into main fuels and consumption sectors, and the
- emissions of SO_2, NO_x, and CO_2.

The data of sulphur and nitrogen emissions were converted into acid deposition values and exceedance of critical loads values using the IIASA RAINS model (see Annex 2 where the RAINS model is presented and

[1] Sustainability shall be understood in broad terms as defined in Halsnæs (1990).

described). In order to ensure consistency, the energy database for the Nordic and the Baltic regions have been supplemented with more general information from the RAINS model. This information includes official energy plans and acid emission control scenarios for the rest of the European countries. Energy consumption data as well as the carbon dioxide emissions were not converted further. For the year 2010, different variations on expectations of the future energy use were available for most of the countries. These values were taken into the database, and then combined into five different scenarios consisting of data for energy consumption, carbon dioxide emissions, and exceedance of critical load values for each of the countries.

The idea of constructing the scenarios has been to investigate the influence of different energy and environment strategies and the potential trade-offs between different environmental goals. The approach focuses on the difference between a strategy where each environmental goal is treated separately as an energy planning restriction, and a strategy where several environmental goals are considered simultaneously.

The scenarios are named:

- **the reference scenarios** representing the values of 1988/89 and 2010 where the values of 2010 were considered to represent energy and environmental planning without giving special consideration to environmental impacts. These scenarios can therefore be said to reflect business as usual.

- **the acid emission control scenario**, where special consideration is given in the energy planning to controlling acid emissions. This could be done by introducing FGD (Flue Gas Desulphurization) and de-NO_x systems into the energy system (this scenario is related only to the year 2010).

- **combined environmental scenarios** representing a number of combinations of values of the efficiency, acid control, and energy conservation scenarios in order to reach fargoing environmental goals in one country or a group of countries (these scenarios are related only to the year 2010). Basically, the combined environmental scenarios were developed to investigate regional effects of applying individual country initiatives or group initiatives for changing the environmental impacts in the region. The following scenarios are interesting:

  - **individual country initiatives**, where isolated environmental efforts in one country (as represented in the environment scenario) are seen in the light of not doing anything specific in the other countries (as represented in the reference 2010 scenario).

  - **Nordic environmental scenario**, where fargoing environmental efforts are introduced in the Nordic countries (represented by the environment scenario) and nothing specific is done in the Baltic region (or outside the region) (as represented in the reference 2010 scenario).

- **Baltic environment scenario**, where fargoing environmental efforts are introduced in the Baltic region (as represented by the environment scenario) and nothing specific is done in the rest of the region (as represented in the reference 2010 scenario). In order to see differences in the regional acidification, it was necessary to include the former East Germany (GDR) and the European part of the former Soviet Union in the Baltic region. In these areas, changes were implied through the RAINS model.

All scenario data have been available for the Nordic countries, while Estonia, Latvia, Lithuania, and Poland are described in less detail due to a lack of accessible information.

The scenarios represent different effects on the sustainability indicators (see section 2.2 for definition and specification).

Acid-control scenarios are directly connected to the introduction of technical control systems on the pipes, without affecting other parts of the energy system, and will therefore have no impact on other environmental indicators like CO_2 emission or total use of fossil fuel equivalents. Oppositly, *combined environmental scenarios* aim at representing the most efficient solution to the entire scope of environmental problems, where possible efficiency improvements, flue gas cleaning systems and energy savings all are taken into account.

As a result of the inavailability of reliable and consistent economic data especially from the Baltic States and Poland, it has not been possible to assign economic cost indicators to the different scenarios on a country level. As a consequence, traditional cost-effectiveness analysis of the implied investments in different energy scenarios cannot be carried out. Recommendations on different investments for the energy system changes could therefore not be based on economic considerations. The final analysis of the effects of the scenarios is a result that is carried out by comparing the environmental indicators and the changes observed from the 1988/89 values. This is described in more detail in chapter 5.

2.2 The environmental indicators

In general, sustainable development implies basically that future generations at least should be able to achieve the same level of welfare as present generations (see also the discussion in chapter 5). This means that an economic stock of capital assets and an environmental capital stock should set the framework for development of society on a global basis. The capital stock concept should be understood in relation to economic replaceable capital as well as in relation to irreversable ecological values (Pearce et al., 1992). However, in order to perform practical and realistic planning under sustainability, it is necessary to operationalize the concept. One way of doing this is to select indicators that shall be conceived as explanatory parameters of measuring progress towards a goal. There is no consensus on how to select and define such indicators. In this project it has been attempted to identify three important indicators relevant for the region, and for energy production and use.

Here the focus has been on environmental and energy indicators and not on economic indicators. The indicators represent environmental issues of society that must be considered from perspectives that are national, regional, and global. These indicators are subject to both short- and long-term influences.

Most often national plans are restricted to the consideration of national needs, costs, and benefits for only a specific energy strategy. With the adaption of the concept of sustainability, it is necessary also to focus on impacts on a larger, even global, geographical region caused by the countries. Simultaneously, the influence of other countries on the environmental state should be considered in future plans. Present-day's energy systems goal tend to have short-term goals (Halsnæs, 1990). But environmental impacts, on the other hand, can persist indefinitely and even be irreversible. Therefore not only must short-term environmental impacts be considered but long-term ones as well. It should be noted that an important implication of the long-term nature of environmental impacts is that the economic and ecological welfare of future generations is influenced by the energy/environmental decisions taken today.

The distinction between short- and long-term environmental effects is important because different time preferences for planning and risk perceptions most likely have a decisive influence when energy/ environmental system goals are to be taken in consideration.

Due to uncertainties and problems in evaluating data, it is not possible to assign ambigious monetary values to all the different short- and long-term environmental impacts of the energy system (Halsnæs, 1990). The environmental goals can therefore (as already mentioned) be treated not as a single monetary decision parameter as in a cost-benefit analysis for environmental investments in the energy sector. Instead in the present analysis we have chosen to use some physical measurements for environmental impact, which seem to supply important information on solving short- and long-term environmental decision problems for the energy system and simultaneously represent indicators of a sustainable development.

Acidification is a complicated factor to consider. It is both a local[2] and regional indicator and gives both short- and long-term[3] effects. Taken in isolation, acid emissions originating from energy use affects the environment close to the energy-consuming source. More likely is that that the acid emissions cause acidification in areas beyond the boundaries of the source country, making regulations an international problem. Also in concern to the timely perspectives, the problem is complex. The effects of acid emissions may be immediate and almost toxic. But more likely, the acidification is seen

[2] By "local" indicator is meant an indicator referring to a homogeneous area where the influence on the area can be made from the inhabitants themselves. By "regional" indicator is meant an indicator referring to an inhomogenous area where there are many different sources influencing the area and where changes cannot be made alone by inhabitants of a smaller part of the region.

[3] The difference between short- and long-term effects lies in the length of time during which the environment has been exposed to the pollutants. Short-term effects are used about pollution damages seen as a consequence of a relatively short time exposure, while long-term effects refer to long-term exposures.

as a long-term accumulative effect (see chapter 4 for further detail). In the present analysis acidification is "measured" on a regional scale. This is also the case of "deposition exceedance of critical loads", in units this is expressed as acid equivalents per hectare per year, used here as an indicator of acidification. The deposition exceedance of critical load values is defined more thoroughly in chapter 4.

CO_2 emissions from energy production and use is a global indicator with both short- and long-term effects. The relationship between global emission levels and their impact on the climate is difficult to assess in physical and economic terms because of fundamental uncertainties concerning available scientific knowledge about processes leading to a climate change. As a global problem the "value" of CO_2 emission reductions are the same for all countries, and emission reduction can therefore be used directly as an indicator for the assessing impact from the energy systems.

Use of fossil fuel equivalents is a local/national long-term indicator for the environmental impact of the energy system. Fossil-fuel equivalents is here defined as a standard measurement of the total gross energy consumption, where nuclear power, hydropower and renewable energy sources are transformed to gross fuel and/or oil consumption in a condensing power plant producing the same amount of electricity (using a standard efficiency factor of 38.5%). The argument for focusing on fossil fuel equivalents is that electricity is an important international commodity, transmitted at low cost to other countries within the region under consideration. It then follows that an export of electricity from countries with relative large nuclear and hydropower resources will preserve exhaustible resources in other countries in the region, which otherwise would be used up. At the same time exported electricity produced by nuclear or hydropower will substitute for fossil-fueled power facilities that contribute acid emissions and CO_2 greenhouse gas emissions.

2.3 Comparability of national data sources

The main sources of the energy database have been offical national energy and environmental plans reporting on present levels of the indicator values, and expectations for the year 2010 (it should be mentioned that the 2010 estimates are extrapolations from presently available data material as referrenced here). In some cases these plans have been supplemented with specific technical data on the potential for energy savings and available FGD or de-NO_x systems. The main national data sources are listed below. A more detailed overview of the national scenario calculations is given in Annex 1.

Main national data sources

- *Norway*: SIMEN (1989).
- *Sweden*: Statens energiverk (1990).
- *Finland*: Ministry of Trade and Industry, Energy Department (1990).

- *Denmark*: Energiministeriet (1990).

- *Lithuania*: Fenhann (1991) and Salay et al. (1993).

- *Latvia*: Fenhann (1991) and Salay et al. (1993).

- *Estonia*: Fenhann (1991) and Salay et al. (1993).

- *Poland*: Cofala and Parczewski (1990), and Szpunar et al. (1990).

All publications are from national official institutions or ministerial departments or have been made by groups with an excellent knowledge of the country.

National energy and environmental planning has been carried out in the Nordic countries using various technological/economic and macroeconomic models. Due to different points of focus and scientific background for the planning activity no single model or model type can be used. It is important to distinguish between analyses made with macroeconomic models/tools and these made by technological/economic models or tools.

Macroeconomic models are based upon assumptions on the behaviour of producers and consumers, and projective parameters for economic development on an aggregate level. "Energy" is usually treated as a parameter related to a production function. This function describes the production levels assuming that energy, capital, labour, and other production resources are used efficiently. In such models environmental goals for the energy system can be introduced by imposing an environmental tax on energy. In the case of, for example, CO_2 emissions, a carbon dioxide specific tax may be put on energy-producing activities, and the macroeconomic model could afterwards be used to calculate the impact on the total energy consumption. In most cases this calculation will not include any detailed assessment on how the reduction of the CO_2 emissions should be carried out. Such calculations often result in relatively high cost assessment for environmental improvements, and to a certain extent this can be explained by the lack of available detail concerning future technological efficiency improvements in such models (UNEP, 1992).

Technological/economic models commonly contain a detailed technical database for the energy supply and consumption system and related environmental impacts, often in the form of emission databases. The different energy technologies are assigned to cost parameters defined as direct economic costs including investment, operational, maintenance, and fuel costs. In these models environmental goals can be introduced as physical planning restrictions in relation to a specific technology or to the energy system in total, ending up with a detailed calculation of a technical character with system costs related to a given environmental policy. The technological/economic models are able to make only an "isolated" calculation of the economic consequences of environmental goals for the energy system. Mulitiplier and price effects are emitted. As a result these models generate only a part of the relevant information needed for an economic assessment of the environmental policy. This is primarily important if fargoing environmental strategies are analyzed, and significant economic effects outside the energy sector can be expected (UNEP, 1992).

Also, in the region considered in this analysis there are large differences in the tools used for deriving the national statistics and plans. The largest difference between the Nordic countries is seen between Norway, where a medium-term macroeconomic model has been used, and Denmark where a technological/economic model has been used. A combined technological/economic and macroeconomic analysis was carried out in the Swedish case using several different planning models. Finland used primarily a detailed planning model describing the energy supply system without giving much detail on possible energy savings. The comparability of the Nordic analysis is extensively discussed in Halsnæs (1989) where references on documentations of the models can also be found.

Very few data have been available for Estonia, Latvia, and Lithuania due to the presently changing political and economic situation. Therefore, as a starting point the scenarios for these countries are constructed as a relatively static projection of the present energy demand supplemented with some modest assumptions on efficiency improvements in the energy supply system.

The Polish scenarios have been made by a technical economic Linear Programming energy system model. A main problem here has been the ability to forecast the economic growth and related industrial energy demand under the present shifting economic conditions. So also for Poland a limited number of scenario relevant values exists.

3 Energy consumption, intensities, and related CO_2 emissions

In spite of its relatively small geographical area, the Nordic/Baltic region is very inhomogenous in terms of its energy resources and its supply, and the use and structure of its energy systems. The measured energy consumption and carbon dioxide emission levels differ, therefore, from one country to another.

3.1 General overview of energy consumption

As a starting point, the energy consumption as of 1988/89 in the countries of the Nordic/Baltic region are compared in Table 3.1.

Table 3.1 Gross energy consumption in the Nordic and Baltic countries 1988/89 (PJ fossil fuel equivalents).

	Electricity production	Other	Total
Norway	849.3	309.0	1158.3
Sweden	1283.9	1144.8	2428.7
Finland	547.9	691.7	1239.6
Denmark	262.0	471.8	733.8
Estonia	-	-	333.0
Latvia	-	-	397.1
Lithuania	-	-	516.4
Poland	1117.5	3769.5	4887.3

Source: National statistics (see Annex 1).

The figures of Table 3.1 represent standardized statistics of the gross energy consumption in the region. Electricity produced by non-fossil energy resources as nuclear or hydropower is transformed to fossil fuel equivalents using a standard efficiency factor, which corresponds to the fuel oil consumption in a standard condensing power plant producing the same amount of electricity. There is a striking difference between the consumption levels of the countries, and it is clear that the electricity sector consumes a considerable part of the total gross energy consumption.

The electricity share of the total energy consumption is relatively high for the countries with a high total energy consumption. The electricity share is as high as about 73% in Norway and about 53% in Sweden representing the high energy-consuming countries of the region (when taking the population sizes of the countries/states and their national products into consideration). In Finland the electricity share is slightly lower, amounting to about 44%, and in Denmark it is as low as about 37%. Poland is characterized by an electricity share of the total energy consumption, on the order of 23% of the total gross energy consumption. The energy consumption in Estonia, Latvia, and Lithuania is relatively low in comparison with the other countries of the region. It was not possible to divide the total energy consuming figure into sectoral consumptions with the available data material. This is also the case in the following tables of this chapter.

An important reason for the above-mentioned differences in energy consumption between the countries is that the national resources for power production vary. A main distinction must be made between countries with relatively large hydropower resources and those relying on burning fossil fuels. In addition to that, main differences appear when nuclear power enters into the power production systems. Table 3.2 give an overview of the power production systems in the countries.

Table 3.2 Structure of the power production systems in the Nordic and Baltic countries (Electricity generation i GWh, 1990).

	Hydro power	Nuclear power	Thermal power	Wind power	Total
Norway	121137	-	464	-	121601
Sweden	71459	65502	5192	4	142157
Finland	10823	18127	22768	-	51718
Denmark	27	-	23353	515	23895
Estonia	-	-	-	-	-
Latvia	-	-	-	-	-
Lithuania	-	-	-	-	-
Poland	3279000	-	118592000	-	121871000

Source: Nordel Annual Report, 1990, Figure S8, p. 91, and Szpunar et al., 1990, Table 5.2).

Norwegian power production is almost totally covered by hydropower. In contrast, the Danish power production is almost totally covered by fossil fuels, more than 95% of which is coal. The structure of the Polish power production system is similar to the Danish, dominated by fossil fuels - coal and lignite covered here about 90% of the production, supplemented by a minor share of oil and gas and hydropower energy product.

Based on the above-mentioned arguments, it can be concluded that the total gross energy consumption is high in those countries where large hydropower and nuclear power are important components of the energy system.

Table 3.3 Energy intensities in the European countries, 1990 level.

Country	Total energy consump-tion PJ	Energy intensity per GDP PJ per bill. US$	Energy use per mill. inhabitants PJ per capita
Norway	1158	12.3	274.9
Sweden	2429	22.9	289.1
Finland	1240	11.4	294.4
Denmark	734	7.0	142.7
Estonia	333	32.6	208.1
Latvia	397	30.3	147.0
Lithuania	516	22.3	139.5
Poland	4887	7.1	127.2
Albania	175	44.9	53.9
Austria	1216	9.3	160.7
Belgium	1932	12.1	196.2
Bulgaria	1403	40.9	155.7
Czech and Slovak Republics	3250	60.1	207.4
France	9056	12.8	161.3
Germany-West	11483	15.9	187.3
Germany-East	3796	39.8	233.6
Greece	921	17.1	91.7
Hungary	1187	43.5	112.5
Ireland	435	13.4	116.9
Italy	6760	7.8	118.5
Luxembourg	134	14.4	359.3
Netherlands	2806	11.8	187.7
Portugal	742	17.0	72.1
Romania	2520	41.8	108.3
Spain	3677	10.1	93.8
Switzerland	1187	6.0	179.6
Turkey	2278	29.8	40.8
United Kingdom	8757	10.5	153.5
Yugoslavia	2056	41.3	86.4

Note. The data from the Nordic countries and Poland are 88/89 level. Comparisons of the energy intensity related to GDP between former centrally planned economies and other European countries must be made with caution due to inconsistent statistical GDP measurement principles.

Sources: Bohm, P.; and Larsen, B. (1992).
RAINS: Official Energy Pathway as updated in 1992.
UN (1990).

In order to widen the scope of the comparison, a broader picture of the energy intensities in a European context is given in Table 3.3.

The energy intensity (in PJ per billion US$) varies between about 6.0 and about 25.0 PJ in 1990 in the European countries, when former centrally planned economies are taken out of the comparison. The intensities of Norway of 12.3 and Finland 11.4 are very close to the European average of 11.9 (again taken the former centrally planned economies out of the comparison), while that of Sweden is slightly higher. Denmark has a relatively low energy/GDP intensity of 7.0. The energy intensities of the former centrally planned economies are generally high in the current data material. This can be a reflection of the low energy prices in most of these countries, but can also partly be due to inconsistencies in the GDP measurements. It is interesting here to notice that the energy intensity (PJ per GDP) of Poland seems to be remarkably low.

A somewhat different picture appears when energy intensity is measured in relation to population size of the countries. Norway, Sweden, and Finland have the highest energy consumption per capita in a European context, and Estonia is also on a relatively high level. In contrast, Denmark, Latvia, Lithuania, and Poland have a lower energy consumption per capita lying close to averages from the European countries. Luxembourg and Albania are here the countries with the highest intensity, Turkey and Portugal with the lowest.

A comparison of energy intensities of the countries is only a general starting point for an investigation of the main determinants for present and future energy consumption in the countries. Differences in energy consumption is generally a consequence of the different structures of the national economies and different energy needs, e.g., as a result of different climatic conditions. The differences can also be attributed to divergencies in the efficiency of the energy systems or in end-use technologies used.

In connection to energy demand forecasts it is very important to be able to differentiate between such background determinants for the energy consumption. This requires, however, a very detailed analysis of the structure of the present energy demand in the eight countries, which is out of the scope of the present study.

As we focus on the Nordic/Baltic region, we instead attempt to outline some of the major differences in the structure of the energy consuming sectors as industry, transport, and households. Table 3.4 shows the sectoral shares of the total gross energy consumption within the countries.

In Norway, Sweden, and Finland industry is the most dominant energy consuming sector, followed by the household sector and, at last, the transport sector. In Denmark the main consumption sector is the household sector, while the industrial and transport sectors are fairly close to each other in use. Industry is more energy-intensive in Norway, Sweden, and Finland than in Denmark, which explains the relatively low energy use in Denmark. It is difficult to go into more detail in comparing industrial energy intensities in the eight countries, because this will require a comparison of energy consumption in relation to well-defined comparable physical products in different subsectors of industry as, e.g., gross energy consumption to produce one tonne of cement. This level of technical detail is not important for this study.

Table 3.4 The structure of total gross energy consumption in 1990 (sectoral shares in percent in relation to total gross consumption in fossil fuel equivalents).

	Industry	Transport	Households etc.	Total
Norway	47	21	32	100
Sweden	42	20	38	100
Finland	44	16	40	100
Denmark	27	27	46	100
Estonia	-	-	-	-
Latvia	-	-	-	-
Lithuania	-	-	-	-
Poland	-	-	-	-

Note: The Finnish data refer to 1986.

Source: Nordisk Ministerråd (1989) (Table 2.31).

Further information on energy consumption in the household and service sectors is given in Table 3.5, where the gross energy consumption in these sectors has been corrected for differences in the amount of heated building area in the countries. The heated area in each country is used here as an indicator of the total "activity level" in the household and service sectors.

Table 3.5 illustrates an important difference in the shares of heat and electricity in the total energy consumption in the household and service sectors between the countries. Electricity is a very dominant energy form in Norway and to a certain extent also in Sweden, but plays a much smaller role in Denmark and Poland (as already seen in Table 3.1). Remarkable differences appear when the energy consumption in the household and service sectors is corrected for variations in the amount of heated building area in the sectors. Norway has a gross energy consumption of 1.98 PJ per mill. building area, falling to 1.77 PJ in Sweden, down to 1.18 PJ in Finland, and only 0.98 PJ in Denmark. One reason for these differences is that electric heating systems play such an important role in Norway and Sweden. In Norway electric resistance heating covered 20% in 1988/89, in Sweden 25%, in Finland 13%, but in Denmark only 6% (sources, see Annex 1).

In such a comparison it is of course important to recognize that due to different climatic conditions the eight countries differ in their demand for space heating. A measurement of this different climatic-related need is the average degree-day concept. The average degree-days is defined as a weighted average of the difference between an outdoor temperature of 17 degrees and the actual daily temperature summed for a total year. Norway has an average degree number of 4264, Sweden 3801, Finland 4252, Denmark 3103 and Poland 3395. This means that there is about 37% difference between the climatic-conditioned need for space heating in Denmark with the lowest number of average degree days and in Norway

Table 3.5 Gross energy consumption for space heating and electricity in the household and service sectors 1988/89 (PJ fossil fuel equivalents).

	Space heating (No.1) PJ	Electricity (No.2) PJ	Total (No1+No2) PJ	Total (No.1+No.2) related to mill.m2 building area
Norway	79.3	211.5	290.8	1.60
Sweden	349.2	617.1	966.3	1.77
Finland	117.3	159.0	276.3	1.18
Denmark	253.4	72.0	325.4	0.98
Estonia	-	-	-	-
Latvia	-	-	-	-
Lithuania	-	-	-	-
Poland	2066.9	477.0	2543.9	4.00

Note: Column 4 refers to the sum of column 1 and 2 related to mill. heated building area in the countries.

Source: National statistics - see Annex 1.

with the highest number - and this is not enough to fully explain the difference in energy intensities in the countries for the household and service sectors, which could be seen from Table 3.5. As mentioned earlier, the total amount of heated building area can be interpreted as an activity indicator for the household and service sectors. There are important differences between the countries in the activity level of the sector, when the building area data are related to the number of inhabitants in the countries. The index of building area related to number of inhabitants is about 65 m^2 in Sweden and Denmark, about 45 m^2 in Norway and Finland, and much less in Poland, about 17 m^2. It can be expected that countries with a relatively low "activity level" in the household and service sectors would have a stronger tendency to growth in energy consumption in these sectors, than countries with a present high "activity level". Even from this analysis it is clear that there are large differences in the countries of the region in terms of energy consumption, structure of energy system, and potential for future trends and developments.

3.2 Scenarios for future energy consumption

Based upon the available official statistical sources and energy and environmental plans, a series of scenarios has been constructed (as mentioned in chapter 2). Most data have been available for the Nordic countries. Due to a very uncertain and unstable economic situation in Estonia, Latvia, Lithuania, and Poland, very few reliable projections on future energy demand and consumption exist. Therefore, only one future scenario has been constructed for Poland, while it was assumed that for

Estonia, Latvia, and Lithuania the energy consumption in 2010 (as represented in the reference 2010 scenario) will be unchanged compared with the 1988/89 level.

In the following, the scenarios are briefly described and can be supplemented with more detail from Annex 1.

REF is the reference scenario reflecting business as usual.

FLUE is the acid emission control scenario, where FGD and de-NO_x systems are assumed to be introduced into the energy systems. The "end of pipe" cleaning systems are introduced without any structural changes in the conversion systems.

ENV is a combined environmental scenario, where efficiency improvements in the supply system, energy conservation and acid control technologies are combined in order to achieve fargoing environmental improvements in relation to total energy consumption, CO_2 emissions, and acid emissions.

The values of the scenarios are shown in Table 3.6. It should be noted that only the reference 1988/89 scenario represents values of energy consumption. All other scenarios are associated with future expectations for energy consumption.

Table 3.6 Scenarios for gross energy consumption 1988/89 to 2010 for the Nordic and Baltic countries (PJ fossil fuel equivalents).

	REF 1988/89	2010 REF	FLUE	ENV
Norway	1158.3	1452.2	1452.2	1576.0
Sweden	2428.7	2983.3	2983.3	2489.4
Finland	1239.6	1477.8	502.5	1256.2
Denmark	733.8	775.1	775.1	517.9
Estonia	333.0	333.0	-	-
Latvia	397.1	397.1	-	-
Lithuania	516.4	516.4	-	-
Poland	4887.0	6994.0	6994.0	-

Source: National statistics, see Annex 1.

The energy consumption growth trend in the energy scenarios is very different between the countries. The gross energy consumption is expected to increase by 25% for Norway in the **REF** scenario from 1988/89 to 2010. An even larger increase on 36% is expected in the **ENV** scenario. In Sweden the increase in the **REF** scenario is on the same level as the Norwegian, namely 23%; the total growth is, however, expected to fall 3% in the **ENV** scenario. For Finland the trends are very close to the Swedish; the **REF** scenario is assumed to grow 20%, and the **ENV** scenario only with 2%. For Denmark this is different since with the **REF** scenario there is an expected increase of only 6% from 1988/89 to 2010, and the energy consumption in the **ENV** scenario is assumed to fall by as much as 29%.

The high increase in the Norwegian **ENV** scenario can be explained partly by an expectation that the electricity share of the total energy consumption will increase in order to achieve reduced CO_2 and acid emissions. Such a strategy is, however, in contradiction to the environmental goal of reducing the total gross energy consumption measured in fossil fuel equivalents and explains the higher level in the **ENV** scenario.

3.3 CO_2 emissions

The level of carbon dioxide emissions is highly dependent upon the structure of the energy system. In the Nordic countries CO_2 emission levels are at high relative to those of other European countries. This can be seen in Table 3.7 which shows the European total CO_2 emissions and intensities for each country corrected for both the GDP and number of inhabitants in the country.

Among the Western countries, Norway and Sweden have the lowest CO_2 emissions per capita. Still, these emissions seem unexpectedly high when one considers the availability of carbon-free resources in the power production systems in these countries (Bohm and Larsson, 1992). Finland, Poland, and especially Denmark have high CO_2 emissions because coal plays a major role in the energy systems of these countries.

In a total European context it is important to notice that the CO_2 emission intensity per capita is especially high in countries with a highly developed economy. One would expect a further increase in European CO_2 emissions with economic development in the poorer parts of Europe.

Going back to a focus on the Nordic/Baltic region, it is clear that differences in CO_2 intensities results from differences in the energy supply structure. In Table 3.8 an overview is given of the CO_2 emissions coming from combustion of fuels for the Nordic and Baltic countries.

The largest contributor to the Norwegian CO_2 emissions is the burning of oil, mainly in the transport sector, as is also the case for Sweden. In Finland and Denmark CO_2 emissions from solid fuels are about the same as from oil. The relative importance of solid fuels as emission sources in Finland and Denmark give a potential for emission reduction because of the high carbon intensity of this fuel. In comparison emission reductions are more difficult to achieve if the transport sector is a dominant source as in Norway and Sweden.

In Table 3.9, the CO_2 emissions are shown as they are represented in the different scenarios.

As illustrated in Table 3.9 the total CO_2 emissions of each country are expected to be almost constant for the Nordic/Baltic region both in the reference level of 1988/89 to the most far reaching environmental scenario in 2010. This is a result of different development tendencies expected in the region in the period.

Table 3.7 Total CO_2 emissions and intensities corrected for GDP and number of inhabitants in the countries as of 1990.

Country	Carbion dioxide emission level Mt CO_2	Carbon emission per GDP (kg CO_2 per US$ GDP)	Carbon emission per inhabitants (kg CO_2 per capita)
Norway	36.0	0.38	8.6
Sweden	61.4	0.35	7.3
Finland	49.7	0.46	9.9
Denmark	56.6	0.54	11.1
Estonia	35.9	1.68	2.6
Latvia	21.9	0.69	12.4
Lithuania	35.8	1.56	1.9
Poland	31.8	3.53	19.9
Albania	9.5	2.38	2.9
Austria	49.5	0.37	6.5
Belgium	95.0	0.59	9.5
Bulgaria	104.5	4.99	11.6
Czech and Slovak Republics	221.5	4.11	14.2
France	345.8	0.33	6.2
Germany-West/East	970.6	0.61	12.5
Greece	64.5	1.21	6.5
Hungary	62.3	2.27	5.9
Ireland	28.6	0.95	8.2
Italy	372.2	0.44	6.5
Luxembourg	9.2	0.95	23.8
Netherlands	123.2	0.51	8.3
Portugal	38.1	0.88	3.7
Romania	205.1	3.70	8.9
Spain	191.4	0.51	4.9
Switzerland	36.7	0.18	5.6
Turkey	114.4	1.50	2.1
United Kingdom	558.4	0.66	9.8
Yugoslavia	129.1	1.87	5.4

Source: Bohm and Larssen, 1992, and UN (1992).

The Norwegian CO_2 emissions are expected to increase in the reference scenario from 1988/89 level to 2010 as well as in the FLUE scenario. The ENV scenario assumes instead a more stable trend. The Finnish situation is very parallel to the Norwegian, where a 38% increase in the reference scenario to 2010 is assumed to be reduced to only a 3% increase in the FLUE scenario. Sweden is expected to have largely increasing emissions in the reference scenario amounting to 129% of the value of 1988/89. This high increase stems from the decomissioning of nuclear plants, which has been

Table 3.8 CO_2 emissions (mill. t) per fuel type in 1990.

	Solid	Oil	Gas	Gas flaring	Cement	Total
Norway	3.8	24.7	6.5	10.3	0.7	46.0
Sweden	13.7	43.2	0.9	0	1.1	58.9
Finland	20.3	26.0	4.3	0	0.7	51.3
Denmark	20.7	22.0	3.1	0	1.0	47.0
Estonia	-	-	-	-	-	-
Latvia	-	-	-	-	-	-
Lithuania	-	-	-	-	-	-
Poland	-	-	-	-	-	-

Note: The Norwegian emissions are here higher compared with those reported in Table 3.7 because flaring of natural gas is included.

Source: UN (1992).

Table 3.9 Scenarios for CO_2 emissions 1988/89 to 2010 (mill. t).

	REF 1988/89	2010 REF	FLUE	ENV
Norway	36	48	48	36
Sweden	61	141	141	75
Finland	50	69	20	51
Denmark	57	57	11	33
Estonia	36	-	-	-
Latvia	22	-	-	-
Lithuania	36	-	-	-
Poland	460	473	473	473

included in the reference scenario. For the same reason the CO_2 emissions are expected to increase by 22% from the level of 1988/89 in the Swedish environmental scenario.

The Danish scenario values differ from the other country scenario values, since the emissions are assumed to be maintained constant in the reference scenario of 2010, and drop by as much as 42% in the environment scenario. This must be seen in relation to the high share of coal-fired power plants in Danish electricity production, which gives good opportunities for CO_2 reductions and relatively optimistic assumptions on energy savings.

For Poland there has only been data for developing a reference scenario, and this scenario projects approximately constant CO_2 emissions from 1988/89 level to 2010. The reference 2010 value is assumed also to illustrate values of FLUE and ENV.

4 Acidification

Acidification of the environment is recognized as one of the most serious current environmental problems. It shows up most visibly in highly industrialized regions such as Europe and eastern parts of North America, and is, therefore, not considered to be a global problem as is the case of carbon dioxide, and other greenhouse gas emissions.

In chemical terms, deposition is characterized as *acidic* when its pH value lies below the natural, undisturbed value 5.6. Today the precipitation throughout Europe is between 4.0 and 4.5 (Alcamo et al., 1990).

The term *acidification* is used most often to describe the process where natural chemical equilibriums of the environment are displaced (as a consequence of acidic deposition) and changes in ecosystems and on surfaces, as for example monuments, occur.

Before analyzing country acidic emission differences between countries and acidification, it is necessary to describe the regional linkages between source and receptor areas of acid deposition.

4.1 Atmospheric transport

Research established in the 70s that anthropogenic emissions of sulphur (SO_2), nitrogen (NO_x), and ammonia (NH_3) are the major causes of acidification (Brodin and Kuylenstierna, 1992). The problem arises as a result of long-range transport of the emissions where pollutants are carried through the atmosphere, undergo chemical transformations to acidic compounds which are then deposited either by rainfalls (wet deposition) or as gases (dry deposition).

After they are emitted, the pollutants remain for some time in the atmosphere before they are deposited to the surface. Each of the pollutants have a unique chemical behaviour and, therefore, different residence time and transportation properties in the atmosphere.

Both nitrogen and sulphur compounds have a residence time in the atmosphere of one to three days. That means that emissions coming from one source (as for example a power plant) can be carried with the wind, perhaps combine with other chemicals and then be deposited up to 1000 kilometres more from the source as acid deposition (rain or dry particles). Typical transport distances of sulphur are about 1500 to 3000 kilometres. About the same distance is expected for oxidized nitrogen (nitrogen oxides) while a greater part of the reduced nitrogen (ammonia) is deposited considerably faster (Lövblad et al., 1992). These characteristics can be seen in Figure 4.1, which shows average transport distances of the three pollutants.

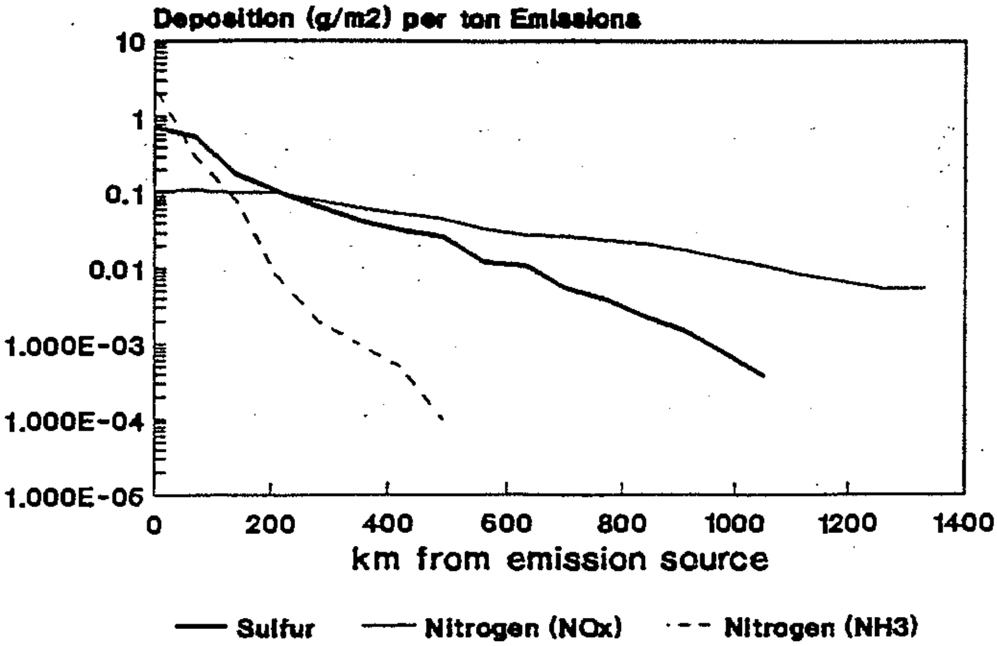

Figure 4.1 Average transport distances for nitrogen, sulphur and ammonia (source: Eliassen et al., 1988).

It can be seen that ammonia is the most "local" pollutant with a relatively high deposition rate close to the source. Nitrogen oxides travel considerably longer distances while the transport behaviour of sulphur lies in-between. Sulphur compounds contribute more to precipitation than the nitrogen compounds and are therefore considered to be the main contributor to acidification.

The long-range transport of air pollutants has major implications on the deposition of air pollutants. Since substances travel typically several hundreds of kilometres before they are finally deposited, acid deposition at specific sites is usually influenced by a large number of emitters. Therefore, in order to decrease deposition at certain places emission reductions have to be considered at many sources. The problem of acidification is a trans-boundary one to be solved by all countries in Europe.

4.2 Emissions and sources

4.2.1 Emission intensities

There are large differences in the emission patterns in Europe of the three pollutants sulphur, nitrogen, and ammonia. Emission intensities (in tons pollutant per capita) for the European countries can be seen in Table 4.1.

Main emitters of *sulphur dioxide per capita* are many of the former Eastern European countries, Bulgaria, the Czech and Slovak Republics, Estonia, Hungary, Poland, Romania, and the former Yugoslavia, all of which have emission intensities above the European average of 67.8 tons sulphur per

Table 4.1 European emission intensities (tons per capita) of sulphur, nitrogen and ammonia as of 1990.

Country	Tons SO_2 per capita	Tons NO_x per capita	Tons NH_x per capita
Norway	20.9	58.2	8.1
Sweden	26.1	8.6	7.3
Finland	57.0	61.7	10.5
Denmark	46.7	50.6	16.6
Estonia	167.5	66.3	
Latvia	44.4	47.0	20.0 *
Lithuania	58.1	45.1	
Poland	99.4	35.1	10.5
Albania	43.1	11.4	9.2
Austria	44.2	38.0	10.7
Belgium	50.7	48.2	10.0
Bulgaria	97.7	42.6	14.3
Czech and Slovak Republics	175.0	43.7	12.2
France	29.3	36.5	12.4
Germany-West	41.2	52.2	9.2
Germany-East	276.6	48.1	13.2
Greece	73.5	35.2	9.3
Hungary	106.8	23.3	14.2
Ireland	44.4	34.1	38.2
Italy	57.5	33.4	6.8
Luxembourg	43.9	104.6	13.4
Netherlands	27.0	45.2	17.8
Portugal	34.8	23.6	6.1
Romania	76.6	23.8	15.3
Spain	62.2	32.1	8.8
Switzerland	11.5	35.7	8.9
Turkey	26.1	11.8	8.2
United Kingdom	67.4	47.6	8.1
Yugoslavia	58.2	18.7	9.0

* denotes a total estimate for the three Baltic Republics.

Sources: RAINS Official Energy Pathway as updated 1992 and national statistics.

capita. Of the Western European countries relatively large emitters are Finland, Greece, Italy, and United Kingdom. In total amounts, the three Nordic countries contribute with approximately 2% of the total European sulphur emission (in total amounts 35433 kt). The Baltic region's contribution (inclusive Poland) to the total is 14%.

The picture is a little different when focusing on the nitrogen intensities. Here Belgium, the Czech and Slovak Republics, Estonia, Finland, Lithuania, Luxembourg, Norway, Poland, and Spain are the principal emitters. The

European average is around 39 kt nitrogen per capita. The Nordic and Baltic regions contribute by 4% and, respectively, 9% to the total European amount of nitrogen emission (total amount 19945 kt).

For ammonia, the emission intensity pattern is different. Here the traditional agricultural countries, Denmark, the Baltics, Bulgaria, Ireland, the Netherlands, and Romania dominate with high intensities. The European average is approximately 11 tons of ammonia per capita.

The differences in the emission intensities of sulphur and nitrogen are closely connected to each country's energy structure. Tables 4.2 and 4.3 show the sectoral contributions of sulphur and nitrogen emissions within the Nordic region. A credible sectoral distribution of emissions in the Baltic region was unavailable, and is therefore omitted.

Table 4.2 The distribution of sulphur dioxide emissions (1000 t) from various sectoral sources in the countries as of 1986.

	Electricity production	Other	Total
Norway	47	58	105
Sweden	139	105	244
Finland	182	142	324
Denmark	194	54	248
Estonia	-	-	-
Latvia	-	-	-
Lithuania	-	-	-
Poland	-	-	-

Source: Nordisk Ministerråd (1989) p. 112.

In total the *Norwegian* sulphur emission estimate is significantly lower than those of the other countries. This is due especially to the low sulphur emissions in the Norwegian electricity and heat production sector as a consequence of the extensive use of low sulphur oil and hydropower. *Sweden* has a large electricity and heat-producing sector that accounts for high levels of sulphur emissions, but the pulp and paper industry also produces large amounts of these emissions. This is also the case in *Finland* where its steel and iron production industries generates large quantities of sulphur. *Denmark,* however, has a different energy sulphur emission structure. Here most sulphur emissions result from high fossil fuel-based electricity production from coal and oil (as seen in chapter 3).

In the case of nitrogen emissions the distribution between the countries is very similar, as can be seen in Table 4.3. For *Norway, Sweden,* and *Finland* most of the nitrogen emissions arise from their large transport sectors. In *Denmark,* again, the electricity production contributes to a large amount of nitrogen oxide pollution.

Table 4.3 The distribution of nitrogen emissions (1000 t) from various sources in the countries in 1986.

	Electricity production	Other	Total
Norway	25	179	204
Sweden	76	228	304
Finland	77	163	240
Denmark	150	110	260
Estonia	-	-	-
Latvia	-	-	-
Lithuania	-	-	-
Poland	-	-	-

Source: Nordisk Ministerråd (1989) p. 114.

4.2.2 Emission scenarios

Estimates for sulphur dioxide and nitrogen oxide emissions have been built into the already-mentioned scenarios. Tables 4.4 to 4.6 show the emissions per country and pollutant. It should be mentioned that the figures given for the Baltic republics are the total for Estonia, Latvia, and Lithuania. It was not possible to perform emission calculations and assessments for these countries individually.

Table 4.4 Emissions in the reference scenario (REF) for the year 1990.

Country	Reference Scenario	
	kt SO_2	kt NO_x
Norway	88	245
Sweden	219	72
Finland	240	260
Denmark	240	260
Estonia	268	106
Latvia	120	127
Lithuania	215	167
Poland	3820	3820

Since the acidification problem is a regional one, which can be investigated with the RAINS model, a few comments on the figures of the scenarios will be made. The figures of the different scenarios are not only represented by the region but values from the rest of Europe also affect the deposition levels in the region. Therefore the RAINS model has been used in

Table 4.5 Emissions related to the Reference Scenario (REF), 2010, the Environment Scenario, and the Flue Gas Control Scenario.

Country	Reference Scenario		Environment Scenario		Flue Gas Control Scenario	
	kt SO_2	kt NO_x	kt SO_2	kt NO_x	kt SO_2	kt NO_x
Norway	116	268	77	206	70	123
Sweden	199	104	156	77	122	144
Finland	252	224	216	183	97	105
Denmark	144	153	89	114	45	48
Estonia	268	106	268	106	268	106
Latvia	120	127	120	127	120	127
Lithuania	215	167	215	167	215	167
Poland	3830	1350	1800	1630	1800	1630

Table 4.6 Emissions related to the Nordic and Baltic Environment Scenarios.

Country	Nordic Environment Scenario		Baltic Environment Scenario	
	kt SO_2	kt NO_x	kt SO_2	kt NO_x
Norway	77	206	116	268
Sweden	156	77	199	104
Finland	216	183	252	224
Denmark	89	114	144	153
Estonia	268	106	268	106
Latvia	120	127	120	127
Lithuania	215	167	215	167
Poland	3830	1350	1800	1630

order to give a more holistic overview of the acidification problem in the region.

The *Reference Scenario* represents national estimates. In the analysis considering effects of the transboundary air pollution similar estimates for the rest of the European countries have been taken from the RAINS Current Reduction Plans[4].

The *Environment Scenario* is organized as follows: for the Nordic region, and Poland the figures are based on national estimates, for Estonia, Latvia, and Lithuania, a total value as estimated in the RAINS scenario Current

[4] See Annex 2 for more comments.

Reduction Plans was used, for the rest of Europe this is also the case though with some exceptions, the figures for the former Soviet region as the former East Germany were changed by applying control devices on values represented in the RAINS Official Energy Scenario. For the sulphur-contributing sector, 100% control was applied to old as well as new coal-fired power plants, for the nitrogen-producing power plants, 100% control was also applied to old and new coal-fired consuming power plants as well as heavy fuel-burning consuming plants. It was necessary to apply these deviations in these regions due to close interrelated meteorological relations in terms of the acidification problem.

The Flue Gas Control Scenario was developed under circumstances similar to the environment scenario. The figures differing between these scenarios are only for the Nordic region alone. It was not possible to develop two distinct scenarios in the whole region due to large uncertainties in the expected developments of the energy system.

The Nordic and *Baltic Environment Scenarios* are combinations of the above-mentioned scenarios. The former represents estimates for the Environment Scenario for the Nordic region while estimates for the rest of the European countries are as in the Reference Scenario (for the year 2010). The latter was developed in reverse order. Here estimates from the Environment Scenario were built in for the Baltic region while those from the Nordic region are as found in the Reference Scenario (year 2010).

In the following, *single country scenarios* will be mentioned. They refer to single scenarios based on the assumption that only one country has applied control devices (estimates used from the Flue Gas Control Scenario) while all other countries are represented in the scenario as in the Reference Scenario (2010).

4.3 Acidic depositions

4.3.1 Depositions and sensitivities of the ecosystems

The effects of anthropogenic emissions can be found on the Earth's surface in the form of depositions. There are large variations in the impact (acidification) of the depositions on the areas that receive them. One factor determining the level of this impact is the sensitivity of the ecosystem.

The sensitivity of the ecosystem varies with factors such as climate, soil type, type of ecosystem, topography, and length of time in which the system was exposed. There is far from complete scientific knowledge on deposition effects, synergistic, or additive effects with other pollutants.

The Nordic region as well as central Europe are sensitive areas.

In Finland, Norway, and Sweden the effects of acidification were first observed in freshwater ecosystems. Fish death, decline of species, and change of vegetation were the first signs of acidification that were reported (Brodin and Kuylenstierna, 1992). Presently, Norway, Sweden, and Finland continue to experience severe acidification. In Denmark, there are reports of acidification beginning at separate locations.

During this century, many areas of southern Sweden are affected by soil acidification. This has also been reported on in Finland and the north of Sweden.

One disorder linked to soil acidification is the extensive forest dieback that has been observed, especially in Germany, Poland, and the Czech and Slovak Republics. In the Nordic countries, there has been no large-scale forest decline, but substantial needle loss in the coniferious forests (a first indication on a possible forest dieback) of Sweden has been recorded.

As already mentioned, the acidification problem is a transboundary one. Therefore, it is of interest to analyze the distribution of the amounts of deposition to the region and the exchange across the borders of the countries of the region. Figure 4.2 gives information about the amount of deposition coming to the whole region and how much of this deposition can be attributed to Nordic as well as Baltic emitting sources.

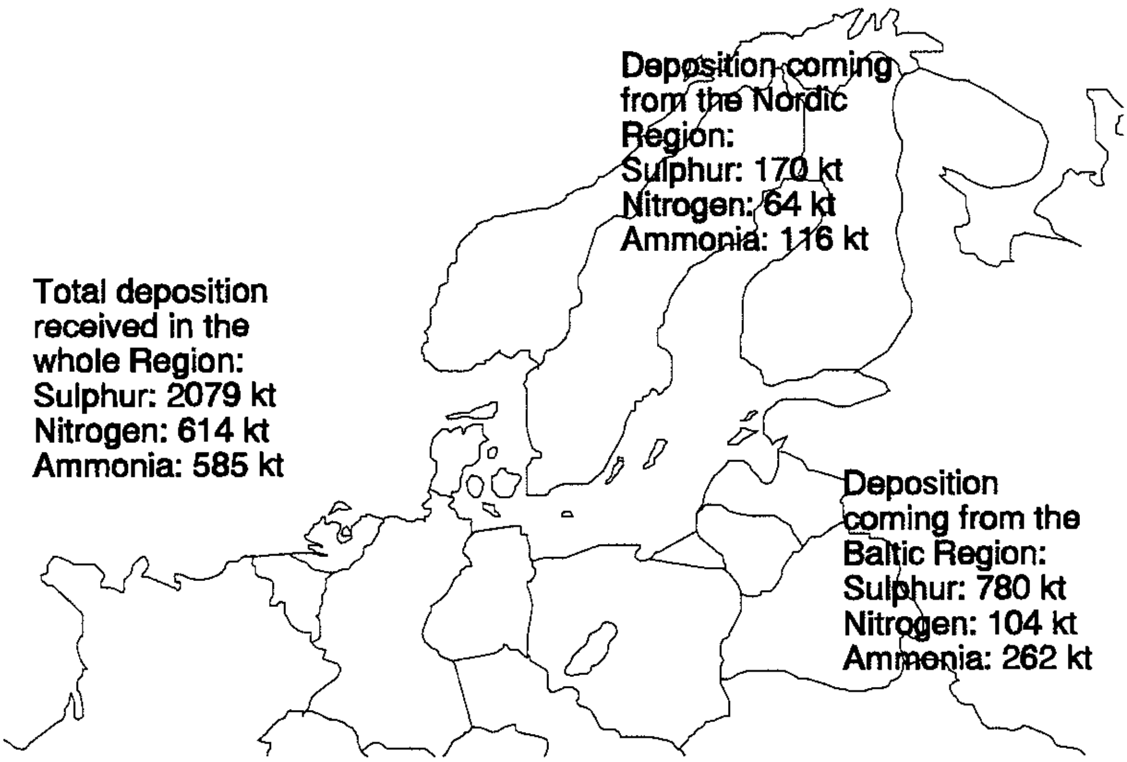

Figure 4.2 Amount of deposition (in kt pollutant in 1990) received in the total region and the deposition amounts coming from the Nordic/Baltic regions. (Source: The RAINS model and national statistics)

It is clear that the sulphur and nitrogen depositions in amount can be attributed mostly to sources outside the Nordic/Baltic region in focus. The ammonia deposition is for a large part coming from the region itself, which supports the tendency seen in Figure 4.1. It can be seen that most deposition in the whole region can be attributed to the Baltic part. However, there are large differences between what is received in the Nordic area compared with the Baltic area. The country differences can be seen in Figure 4.3.

Clearly, Poland has by far the largest deposition loads while Denmark has the smallest. Naturally, the country sizes here play a role and the figure

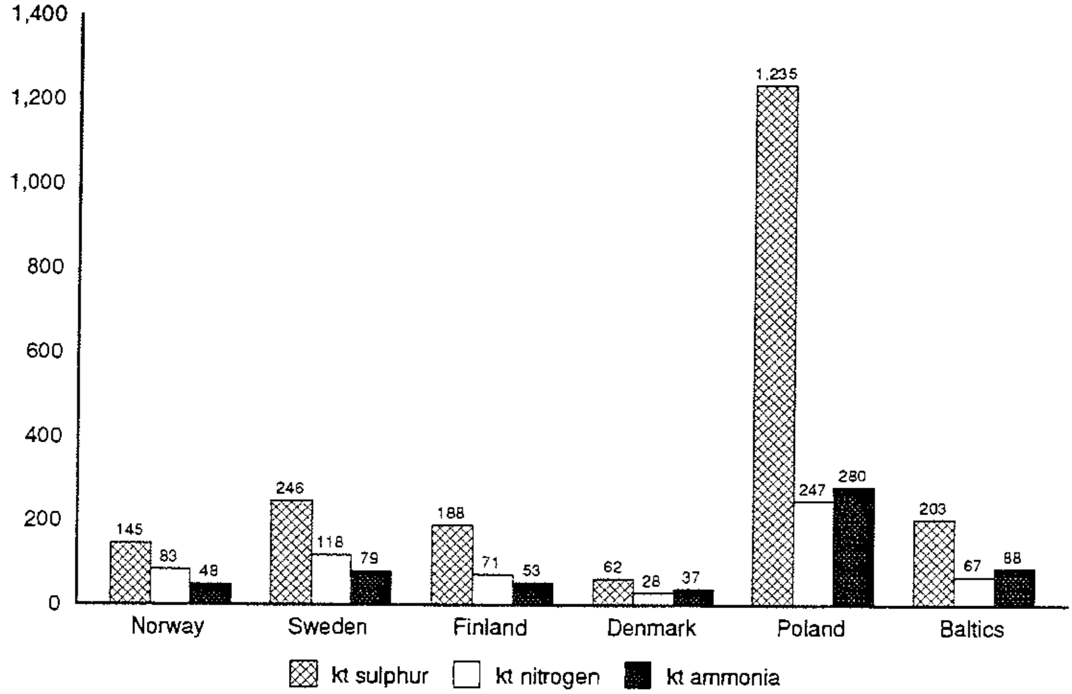

Figure 4.3 The deposition loads in 1990 coming to each of the countries of the region. Units are kt sulphur in S, kt nitrogen in N, and kt ammonia in N.

shall just be seen as an orientative illustration. It is more interesting to investigate which sources account for the different depositions. Tables 4.7 to 4.12 show for each of the countries in the region the deposition loads in the countries, the origin of the incoming deposition, and what percentages each source contributes to the total deposition load in the country.

Table 4.7 Amounts and percentages of pollutant deposition in Norway in 1989/90.

	Sulphur deposition		Ammonia deposition		Nitrogen deposition	
	kt	% of total	kt	% of total	kt	% of total
Total deposition received in Norway	145		48		83	
Deposition coming from						
- Norway	12	8	15	31	7	8
- The Nordic countries*	10	7	6	13	5	6
- The Baltic area	10	7	3	6	4	5
- Others	113	78	24	50	67	82

* These estimates do not include the contribution from Norway.

Table 4.8 Amounts and percentages of pollutant deposition in Sweden in 1989/90.

	Sulphur deposition		Ammonia deposition		Nitrogen deposition	
	kt	% of total	kt	% of total	kt	% of total
Total deposition received in Sweden	246		79		118	
Deposition coming from						
- Sweden	33	14	23	29	3	3
- The Nordic countries*	25	10	15	19	18	15
- The Baltic area	32	13	9	11	13	11
- Others	156	63	32	41	84	71

* These estimates do not include the contribution from Sweden.

Table 4.9 Amounts and percentages of pollutant deposition in Finland in 1989/90.

	Sulphur deposition		Ammonia deposition		Nitrogen deposition	
	kt	% of total	kt	% of total	kt	% of total
Total deposition received in Finland	188		53		71	
Deposition coming from						
- Finland	37	20	23	43	11	16
- The Nordic countries*	8	4	3	6	5	7
- The Baltic area	22	12	8	15	10	14
- Others	121	64	19	36	45	63

* These estimates do not include the contribution from Finland.

Table 4.10 Amounts and percentages of pollutant deposition in Denmark in 1989/90.

	Sulphur deposition		Ammonia deposition		Nitrogen deposition	
	kt	% of total	kt	% of total	kt	% of total
Total deposition received in Denmark	62		37		28	
Deposition coming from						
- Denmark	14	23	23	62	2	7
- The Nordic countries*	1	1	1	3	0	0
- The Baltic area	3	5	1	3	1	4
- Others	44	71	12	32	25	89

* These estimates do not include the contribution from Denmark.

Table 4.11 Amounts and percentages of pollutant deposition in the Baltic states in 1989/90.

	Sulphur deposition		Ammonia deposition		Nitrogen deposition	
	kt	% of total	kt	% of total	kt	% of total
Total deposition received in the Baltic states	1235		280		247	
Deposition coming from						
- The Baltic states	611	49	178	64	55	22
- The Nordic countries	8	1	4	1	7	3
- The Baltic area*	7	1	3	1	3	1
- Others	609	49	95	34	182	74

* These estimates do not include the contribution from the Baltic states.

Table 4.12 Amounts and percentages of pollutant deposition in Poland in 1989/90.

	Sulphur deposition		Ammonia deposition		Nitrogen deposition	
	kt	% of total	kt	% of total	kt	% of total
Total deposition received in Poland	203		88		67	
Deposition coming from						
- Poland	63	31	52	59	9	13
- The Nordic countries	8	4	3	3	6	9
- The Baltic area*	32	16	8	10	9	13
- Others	100	49	25	28	43	64

* These estimates do not include the contribution from Poland.

In general, it appears that the source of most of the deposition on the individual countries lies within the countries themselves. In the case of sulphur and nitrogen the deposition comes for the most part from sources outside the regions, as expected. However, the Baltic states and Poland are exceptions in that their high deposition percentages of sulphur and nitrogen appear to originate locally. This must be seen as a consequence of the energy structure in this region. Norway is a country which is especially exposed to pollution from outside the Nordic/Baltic region. Sources outside this region contribute to the total deposition amounts of sulphur and nitrogen by 78%, and 82% respectively. Denmark receives a large percentage of its deposition from countries outside the region. In the case of ammonia depositions, each country is the main source of its received deposition, as already mentioned. Each of the three pollutants contribute differently to the acidity and to the acidification potential as well.

The emission scenarios commented on in section 4.2.2, referred only to sulphur and nitrogen oxide emissions. However, these tables show that ammonia is also a major source of acidic deposition. Table 4.13 shows deposition estimates converted to acid equivalents per hectare per year in the countries considered in the report. The first deposition estimate is based on the contribution from sulphur and nitrogen oxide emissions while the second expresses the total acidity (sulphur, nitrogen oxides, and ammonia emissions).

Table 4.13 The differences in deposition values based on sulphur and nitrogen oxide emissions and sulphur, nitrogen oxides, plus ammonia emissions (the total acidity).

Country	$SO_2 + NO_x$ acid eq/ha yr 1990	$SO_2 + NO_x + NH_x$ acid eq/ha yr 1990	Absolute deviation percentage
Norway	445.8	553.9	20
Sweden	532.2	661.4	20
Finland	504.6	619.0	18
Denmark	1273.9	1887.6	33
Estonia			
Lithuania	1282.82 *	1680.79 *	27
Latvia			
Poland	2727.0	3367.9	19

* These are total estimates for the three Baltic states.

Source: RAINS and own scenarios.

On comparing the deviation percentages, we can see that the fraction of ammonia on the total deposition estimate is very similar in all countries. As the countries do not have a large exchange of ammonia, the contribution from the ammonia emissions to the deposition estimates can be regarded as a background estimate. The countries themselves will not lower this deposition by imposing changes in the energy systems. Therefore, deposition levels will in the following be referred to as total deposition levels based upon sulphur and nitrogen emissions of the countries only. The contribution from ammonia sources will be seen as background deposition and is not accounted for here since our focus in this report is to indicate changes imposed by the energy system. Figure 4.4 shows the acid deposition in the region as of 1990.

The figure shows that there are regional differences in the deposition levels, and that these differences exist even within the countries themselves (see Sweden, Norway, Finland, and Denmark).

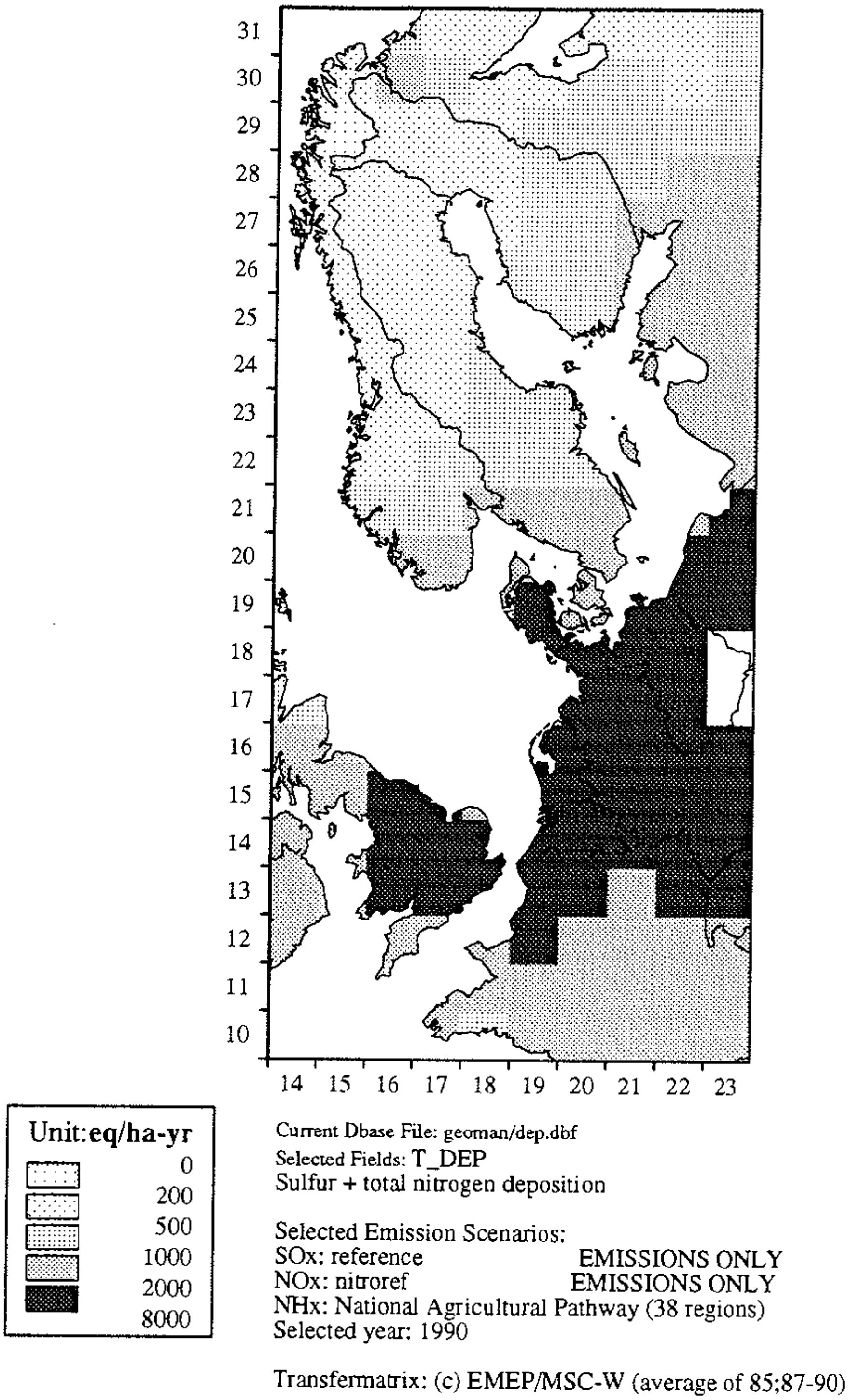

Figure 4.4 Acid deposition in the Nordic/Baltic region in 1990. (Source: The RAINS model and national statistics)

4.3.2 Critical loads of acidification

In an attempt to assess the effects of emissions on the ecosystem and decide on emission abatement strategies, the concept of *critical load* has been expressed. It is defined as *"A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge"* (UN-ECE, 1988). The concept has been developed scientifically in response to a political request.

In practice, the critical load value represents an estimate of the maximum level of pollutant at which harmful effects on the particular ecosystem of concern are unlikely to occur. It therefore represents a threshold value occurrence of harmful effects in forest soils and fresh water.

The critical load value refers to a dose of pollutant deposition exposed to a defined area over a specified period of time. Typical units are acid equivalent per square kilometre per year or gram acid deposition per square metre per year. These values may cover one or more pollutants.

Five different classes of relative sensitivity of the ecosystem have been chosen (based on research on the Scandinavian region that is considered to exhibit the highest level of acidification). These can be seen in Table 4.14.

Table 4.14 Relative sensitivity classes and critical load values.

Relative sensitivity class	Critical load eq per ha per yr
1	> 2000
2	1000-2000
3	500-1000
4	200-500
5	0-200

Source: Hettelingh et al., 1991.

The higher the sensitivity class (and lower the critical load) the more sensitive to the effect is the ecosystem considered to be.

A comprehensive amount of work has been performed (and is continuously improved) in European countries for establishing a European critical loads map. This work has been carried out under the United Nations Convention on Long Range Transboundary Air Pollution. Critical load values have been determined for the whole European area and mapped in EMEP[5] grid cells (which is approximately 150 km x 150 km). This is made for total acidity, sulphur, and nitrogen.

The following Table 4.15 shows critical load values for the region considered in this report. The values are given as they have been set in Hettelingh et al. (1991) and represent country averages.

It should be noted that the critical load values stated in Table 4.15 are given as the value representing the most sensitive areas in the countries. In Sweden, Denmark, and Poland there are areas where the critical load values

[5] EMEP: European Monitoring Evaluation Programme.

Table 4.15 Critical load values for the Nordic/Baltic region.

Country	Critical load value (actual acidity - 5-percentile) eq per ha yr
Norway	200
Sweden	200
Finland	200
Denmark	1000
Estonia	200
Latvia	200
Lithuania	1000
Poland	1000

Source: Hettelingh et al., 1991.

are in a lower sensitivity class. It should also be noted that the values are based upon measures of single locations in the countries and are extrapolated and weighted in order to present an overall national picture. Hettelingh et al. (1991) describes in detail how this is carried out in practice.

Values assigned to the grid cells are expressed in terms of percentiles. *The 5 percentile* reflects the value at which *95% of the total area in the cell will be protected* (if the deposition does not exceed this value). The 5 percentile critical loads are the most commonly utilized. The concept *"exceedance of critical loads"* is used as an indicator of the excess of current deposition loads over the critical load percentile.

The actual deposition levels, together with technical, social, and economic realities that reduce the emissions, indicate that the emission reductions required to achieve critical load values cannot be implemented by a simple step within a few years. The concept of *target load* is therefore used to indicate goals that countries consider may be achieved within a given time frame. Target loads are nationally set, taking into account not only the environmental sensitivity but also technical, social, economic, and political considerations by individual countries. This value may be set at the same level, higher, or lower than critical loads. Target loads below critical loads may be motivated either by the inclusion of a margin safety factor due to uncertainties in critical load values (to ensure that undamaged ecosystems will remain protected). The difference between critical loads and target loads is small (Brodin and Kuylenstierna, 1992). In the following only critical load values will be referred to.

With the deposition levels depicted in Figure 4.4, Figure 4.5 that follows shows exceedance of critical load values (5 percentile critical loads).

Note again the differences within the countries and within the region. Note also that the critical load values in Table 4.15 are national average values and that Figure 4.5 gives a more detailed picture of both acid deposition and exceedance values.

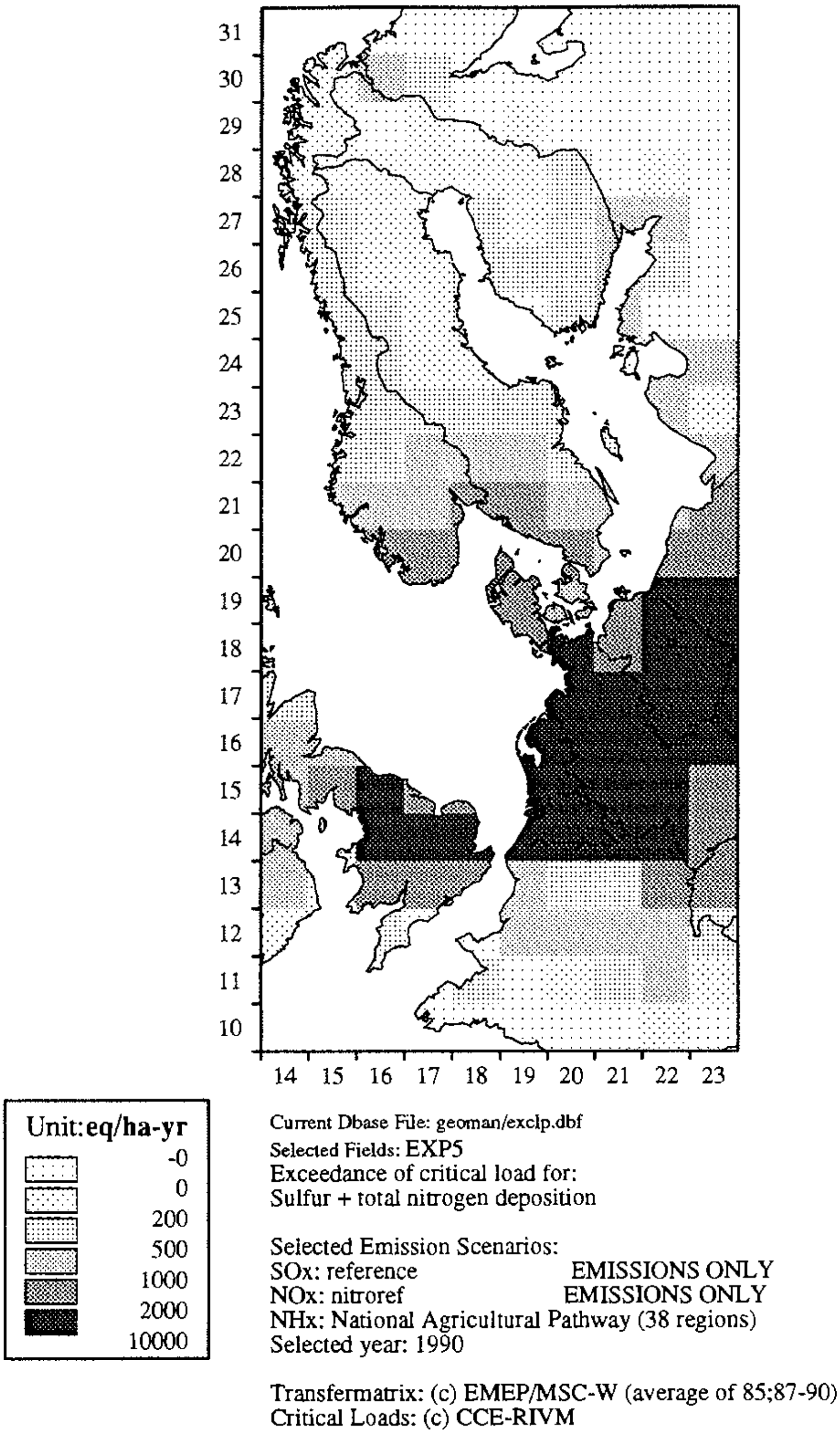

Figure 4.5 Exceedance of 5 percentile critical load values in the region 1990. (Source: The RAINS model and national statistics)

Comments on the critical load values

The critical load map is based on data on critical load values for surface waters and forest soils (as estimated by Coordination Center for Effects, RIVM, Bilthoven, The Netherlands) supplemented by data from the individual countries. For countries which have not contributed national data, the Coordination Center has used databases from the International Institute for Applied Systems Analysis, and the Winand Staring Center. Approximately 50% of the European countries have performed national contributions to the mapping exercise. The calculational methods behind the national studies are dominated by two methodologies for the assessment of the critical load values in the countries. The critical load values for the different receptors are combined into one cumulative distribution in each of the EMEP cells. The methodologies shall not be commented on further here. Details can be found in Hettelingh et al. (1991).

The derivation of critical load values is difficult and characterized by large uncertainties. Some obstacles are (according to Kämäri et al., 1992) the estimate of depositions, especially for nitrogen; variations in deposition loads between different sites and the relatively large aggregation level (the grid cell sizes); differences in sensitivity of various ecosystems to the occurrence of depositions; extrapolations of relatively few local monitoring data to generalize a larger area; comparability of measures and calculations between different institutions and countries for obtaining a European map; and difficulties in assessing the filtering factor of the different ecosystems on air deposition concentrations in order to compare the deposition with the receiving surfaces.

The term exceedance of critical load values is commonly used to express the state of the ecosystem. However, there is no scientific knowledge on the precise correlations between the deposition levels and critical load values. It is unclear whether an exceedance factor over the critical load values of, for example, 10 has the same effect on biosystems as exceeding the critical load values by a factor of 100.

Despite the uncertainties and difficulties in establishing critical load values, it is an internationally accepted measure of emission reduction. This report will also use the term as a measure of the acidification in the region.

4.3.3 The acidification indicator

For assessing the effects of the emission scenarios reported on in section 4.2.2, the regional Acidification INformation and Simulation (RAINS) model was used to connect emission sources with receptor areas as was shown in Figure 2.1. The model is described briefly in Annex 2. Tables 4.16 and 4.17 show results of the calculations. It was decided to express results in terms of exceedance of critical load values as absolute units (e.g., acid per hectare per year). The values given are country averages.

The scenarios express the effects of the various schemes in emission regulations. It is clear that the reference scenario for 1990 results in the highest exceedances of critical load values (5 percentiles). The other scenarios representing expectations for the year 2010 result in significantly lower exceedance values. A comparison of these scenarios does not reveal large differences in exceedance values.

Table 4.16 Exceedance of critical load values (in eq/ha yr) in the various emission scenarios and countries (country averages).

	REF 1990	REF 2010	ENV 2010	FLUE 2010	NORD 2010	BAL 2010
Norway	507.6	398.7	370.1	360.7	376.4	390.3
Sweden	373.7	253.6	208.1	190.8	230.1	232.2
Finland	201.1	129.7	99.7	70.8	116.5	117.2
Denmark	1196.5	720.9	647.9	598.3	666.8	696.2
The Balt. Rep.	411.5	262.3	145.1	137.1	255.5	205.5
Poland	2481.5	1776.3	1107.4	1098.0	1770.6	1082.2

Source: The RAINS model and national statistics, see Annex 1.

Table 4.17 Exceedance of critical load values (in eq/ha yr) related to the individual Country Scenarios.

	Country scenario				
	Norway	Sweden	Finland	Denmark	Finland
Norway	377.7	396.7	395.2	392.2	388.3
Sweden	245.1	240.5	243.9	242.7	235.3
Finland	127.9	128.5	92.8	127.4	120.3
Denmark	716.8	710.4	719.6	637.1	696.6
The Balt. Rep.	260.8	261.4	254.3	257.3	205.6
Poland	1775.0	1775.9	1774.6	1768.7	1084.2

Source: The RAINS model and national statistics, see Annex 1.

The largest effects of regulation schemes can be seen in the Environment and the Flue Gas Control Scenario. Here decreases in exceedance values are especially evident in Sweden, Finland, the Baltic states, and Poland. Whether or not the actural difference between these two scenarios gives visible changes in the impacted areas remains an open question.

The effects of incentives to lower pollution levels expressed in the Nordic/Baltic scenarios are small. Emission reductions in the Nordic region alone gives small reductions in the countries themselves, and practically no side benefits in the Baltic region. Incentives in the Baltic region alone give exactly the same picture. The results of the scenario run are closely connected to both the atmospheric relations and the fact that most of the deposition coming to the regions results from long-range transboundary emission transport from the rest of Europe. Another explanation can be that the Nordic countries already have reduced their contributions significantly so further reductions can be carried out only on a small scale and with only a small visible effect.

The individual country scenarios can be seen to result in depositions close to the reference values. Only smaller reductions are observed for those countries applying the regulation schemes. The largest reductions in exceedance values are found for Finland and correspond to the exceedance values also observed in the Flue Gas Control Scenario. The effects of the single country initiatives prove to be rather small and cannot be said to have a significant influence on the exceedance values in either of the regions. Naturally, this conclusion corresponds very well with the small "exchange of deposition" between the countries of the region.

It should be mentioned that it is unclear whether the exceedance values for, e.g., Poland will be as damaging as the lower exceedance values of Finland and Sweden (it is unknown whether there exists a linear relationship between the deposition levels and the effects seen in the environment). Therefore it is also unclear whether the differences that can be seen on comparing the scenario values will have a biological effect on the ecosystems exposed to the depositions. No conclusion on the acidification measures shall be made here.

5 The coherent view

Sustainable development has received almost universal acceptance as an ideal for the development of our societies now and in the future (Munn, 1992). However, within the concept there lies many different meanings and perceptions and it is not in itself an operational phrase. Worldwide much effort has been put into operationalizing the concept. This chapter discusses some of the problems that arise in doing this and analyzes the effects of performing coordinated energy and environmental planning under the concept of sustainable development for the region in focus.

5.1 Sustainable development of the energy system

Seen from an energy perspective, there are three characteristics which can be valuable in determining *the sustainability of energy systems or plans* (see Halsnæs and Mackenzie, 1990). These are:

- How the ecosystem is influenced both in the short and long terms by pollution sources. The influence and the energy system production shall be judged in relation to the prospects for future use and availability of energy resources, as well as to the deterioration of the quality of the ecosystems.

- How the energy system affects the wealth of future generations with respect to the stock of capital wealth and productive resources such as fuels and other raw materials; the quality of the ecosystem comprising system characteristics such as generic variation, population levels of different species and more human-specific goals for the environment.

- National and international equity.

(See Halsnæs and Mackenzie (1990) for more details). Often the literature refers to environmental and economic sustainability (see, for example, Matheson, 1990). However, it is the viewpoint of the authors that the concept of sustainability can be defined operationally more easily if one works with a smaller system. The energy system is one example of a subsystem within international and national societies and is at the same time an important part of both the environment and economic system, so that changes in these two systems are sensitive to changes in the energy system.

The determination of the sustainability of an energy system and how coordinated planning can be carried out within this frame inherently means that arguments concerning a number of problem areas, indicators for measuring these, and ideas on how they can be compared must be presented for.

Taking the Nordic/Baltic region as an example, it is clear there are some selections which must be made in order to make a coordinated energy and environmental plan or judge the sustainability of the energy system. In practice this implies the following steps:

- Selection of energy and environmentally related problem areas which are important for the region and may be limiting factors for the region's development. This shall be seen in connection with the points defining the sustainability of the energy system.

- Selection of indicator values or other operational measures that can be used to measure development and achievement of goals in operational terms.

- For each of the indicators or measures goals or targets and restrictions (criteria) must be developed for reaching these. The goals, targets, and criteria may be quantitatively or more qualitatively defined. The formulation of the criteria can be based upon social assessment and restrictions on how the goals/targets can be reached. They do not have to be associated with restrictions imposed by the energy system alone.

- Indicator values must finally be compared in relation to the above mentioned criteria and goals/targets. Based upon this comparison, a judgement about the sustainability of the energy system can be reached.

Each of the points may seem obvious, but nevertheless they imply many complexities. Some of these will be discussed in the following.

5.1.1 Problem areas

Seen as a whole, the Nordic/Baltic region as has already been mentioned, has three problem areas which are directly connected to coordinated energy production and use, and therefore relevant for the sustainability of the energy system. These are acidification of the environment, climate change, and depletion of exhaustible resources. The problem areas have been noted earlier and argued for in chapter 2.

Looking more closely at these problems, the climate change problem cannot be said to be specific for the region. However, the problem must be viewed as unavoidable in today's agendas since it is an international issue of great concern. Thus, planning under sustainability cannot be evaluated only from a national or regional view. A high priority must be given to global perspectives as well.

5.1.2 Indicators

The argument was given in chapter 2 that some indicator values for measuring the current state of the problem areas and how they develop in the future were necessary. Here, exceedance of critical load values was selected as a measure of the acidification state, the level of carbon dioxide emission as a measure of the impact on the global climate change, and the use of fossil fuel equivalents as a measure of energy use and the options for avoiding the exhausting of resources.

In general the selection of these indicator values is not easy. Currently, there are many discussions in the literature to select proper indicator values for problem areas to consider under the sustainability concept (see for example Munn, 1992, or Matheson, 1990). However, these authors generally look at the problem from the perspective of their own countries. This report has considered only three indicators for which it would seem reasonable to reach a more regional consensus. It should be emphasized that indicators shall be regarded merely as explanatory in order to assess the state of the problem areas and judge whether changes are in accordance with the principles of sustainable development.

The indicators can be selected in many ways. To do this for the region we have used the following criteria:

- The indicators shall be measurable in terms of available data which is scientifically credible, published in the literature and accepted as the most accurate possible.

- The indicators must be easily understood by anyone involved at any stage in the process of planning and judging the sustainability of the energy system (e.g., decision maker, planner or representative from the energy supply and demand sector).

- The indicators shall represent internationally comparable values in order to be used as a basis for coordinated planning in a larger geographical region.

We realize that problem areas exist which are not easily quantifiable, and that the selection of indicators may involve large political interests. In this project we have sought to select indicators which are relatively accepted in large areas of the world - politically as scientifically.

5.1.3 Goals for indicators

Goals must be defined before it is possible to assess the development of energy systems. These goals should be related to timely set point values or states of the indicators but also to the rate for changes. There are many ways to specify the goals. The most commonly used goals are either

- effect-oriented, meaning that the focus is on the impacts produced on the ecosystems, namely technical, economic or ecological,

or

- source-oriented, meaning that the focus is on the changes in the source which lead to the effects. These goals will most commonly be related to technical parameters associated with the energy system and its structure.

Setting goals in quantitative or qualitative respect for the indicators is in practice a highly political task. The goals must be based upon relevant scientific and technical information as well as economic aspects together with more profound social aspects such as cultural, ethical, and political preferences.

Looking upon the indicators of the region, the acidification problem has been assigned goals in recent years. The critical loads concept (or perhaps more the target load concept) can be interpreted as an effect-oriented goal for assessing the acidifying deposition levels in various countries. The criteria for attaining this goal is to minimize the exceedance of critical load values given the need for energy and economic restrictions of the countries.

There has not yet been formulated such specific goals/targets for the other indicator values. However, a worldwide carbon dioxide emission protocol has been established to put restrictions on the emissions coming from the sources (source-oriented goals). This protocol has been formulated and entered into force only recently and its effects cannot be seen as yet.

Naturally, the specification of goals/target setting is associated with many obstacles. Far from all indicators can be formulated in quantitative terms complicating the formulation of goals/targets. Another problem is the more human-related negotiations and agreements resulting in goals/targets formulation. Different countries have usually different perceptives of how important and influential one problem area should be regarded and therefore also on how strict the goals/targets for energy systems development should be expressed. This project has not sought to establish goals for the indicators, a highly political task, but concentrates only on the acidification critical loads concept.

Establishing criteria within which the goals shall be reached is somewhat easier. Often there are simple criteria such as minimizing monetary costs on the level of energy production.

5.1.4 Comparison

Finally, it is necessary to provide a framework within which the indicator values can be discussed and compared. A comparison would basically imply that each of the indicators should be related to the criteria or goal setting, and that a holistic and general conclusion should be drawn from this comparison.

In theory it is possible to combine or aggregate data from a series of indicators to produce a dimensionless index of energy sustainability. However, this idea is problematic in practice. First, because of difficulties in establishing and agreeing on indicator definitions and their measures. Secondly, to find a basis for agreement on the relationship between the indicators and their relative weighting factors. It is debatable whether a reasonable set of weighhting factors could be assigned and would have sufficient credibility to be useful.

Within this problem lies also an implicit prioritorization of the problem areas and their importance for attaining energy sustainability. Such a prioritorization should be expressible in quantitative terms and there should be a certain consensus on the prioritization. Seen from a national perspective this can be achieved to an acceptable level at least in the national energy planning areas. Internationally, obstacles arise where each nation looks differently upon the problem and the problem areas, and would have to also consider unique aspects of national jurisdictions and limitations. It is obvious that even with a region as small as the Nordic/Baltic one, a prioritorization of the three problem areas would be highly different. Each of the countries has its own resource and economic limitations, and environmental interests.

This project has therefore not attempted to express the indicators in one measure. Instead it is assumed that an analytical comparison can be performed that assumes the benefits derived from invoking the different scenarios.

5.2 Results

Indicator values for the different scenarios and countries are summarized in the following Tables 5.1 to 5.4.

Table 5.1 Indicator values for the Reference Scenario, 1990.

Country	Energy consumption PJ	CO_2 emission Mt	Exceedance of critical load eq/ha yr
Norway	1158	36	508
Sweden	2429	61	374
Finland	1240	50	201
Denmark	734	57	1197
The Baltic Republics	1247	94	412
Poland	4887	460	2482

Indicator values of the individual Country Scenarios are not summarized here since they represent no significantly different values and are merely appropriate combinations of the measures above.

In order to compare the three indicators in each scenario and each country, the values from the individual countries as they were estimated to be in the Reference scenario 1990 (Table 5.1) were used as baseline for deriving index values where reference 1990 values were set to index 100.

Table 5.2 Indicator values for the Reference Scenario, 2010.

Country	Energy consumption PJ	CO_2 emission Mt	Exceedance of critical load eq/ha yr
Norway	1452	48	399
Sweden	2983	141	254
Finland	1478	69	130
Denmark	775	57	721
The Baltic Republics	1247	94	262
Poland	6994	473	1777

Table 5.3 Indicator values for the Environment Scenario, 2010.

Country	Energy consumption PJ	CO_2 emission Mt	Exceedance of critical load eq/ha yr
Norway	1452	48	370
Sweden	2983	141	208
Finland	1478	69	100
Denmark	775	57	648
The Baltic Republics	1247	94	145
Poland	6994	473	1107

Table 5.4 Indicator values for the Flue Gas Control Scenario, 2010.

Country	Energy consumption PJ	CO_2 emission Mt	Exceedance of critical load eq/ha yr
Norway	1452	48	361
Sweden	2983	141	191
Finland	503	20	71
Denmark	775	11	598
The Baltic Republics	1247	94	137
Poland	6994	473	1098

The results can be seen in Figures 5.1-5.5, which show the index values for each country and scenario. Based on the arguments from the previous section, no attempt has been made to produce one dimensionless measure or "sustainability index" referring to one total score of the three indicators. Instead, each of the three problem areas are represented by indicator values that must be compared and weighted before a final conclusion can be made. It is the viewpoint of the authors that the comparisons and final weight preference settings ought to be made by decision makers.

It should be remembered that the indicator values differ markedly in terms of how they are measured and the sources responsible for the values. The emissions of carbon dioxide and energy consumption level are both measured of the countries themselves where the goals (if defined) would be source-oriented. The acidification indicator, exceedance of critical loads, is related to a more effect-oriented measure. The exceedance of critical loads, on the other hand, is a measure "created" not only by emissions from the country itself but by other counties as well. This means that the regulation of this measure cannot be made by a single country receiving the deposition, but in combination with other countries that contribute to the deposition level. This means that the achievement of a goal (critical load value) in one country shall be recognized in other countries also, and that the acidification issue is prioritorized equally high in the countries that are sources of the deposition.

In general, the index values of the scenarios show a tendency in which each country expects (compared to the reference 1990) an increase of fossil-fuel combustion, and attendant carbon dioxide emissions together with a lowering of the exceedance of critical load values as a result of commitments already made for decreasing acid emissions in the whole of Europe.

The Environment scenario shows that some countries have formulated relative strict regulations for decreasing the carbon dioxide emissions. In the entire Nordic region it is obvious that some specific considerations have been made to hold the carbon dioxide emissions at the level of 1990 or even lower. The Flue Gas Control Scenario illustrates even more the extreme technical options for decreasing energy use and carbon dioxide emissions. Finland is one example where energy use is lowered by as much as 60% from the reference 2010 scenario, and 70% with respect to carbon dioxide emissions. Denmark has a similar strategy, though only related to a 80% reduction in carbon dioxide emissions. It is clear that the efforts laying behind these scenarios have a positive effect on the exceedance of critical load values (compared to the reference 1990) in the whole region, and that the largest reductions are observed in the Baltic area.

Overall it can be seen that the Environment scenario (referring to the whole region) does not provide significant achievements in terms of the acidification indicator compared with the Baltic Environment scenario and the individual country scenarios. Consequently, the Environment scenario should not be implemented in the whole region if the acidification indicator is considered to be the most important.

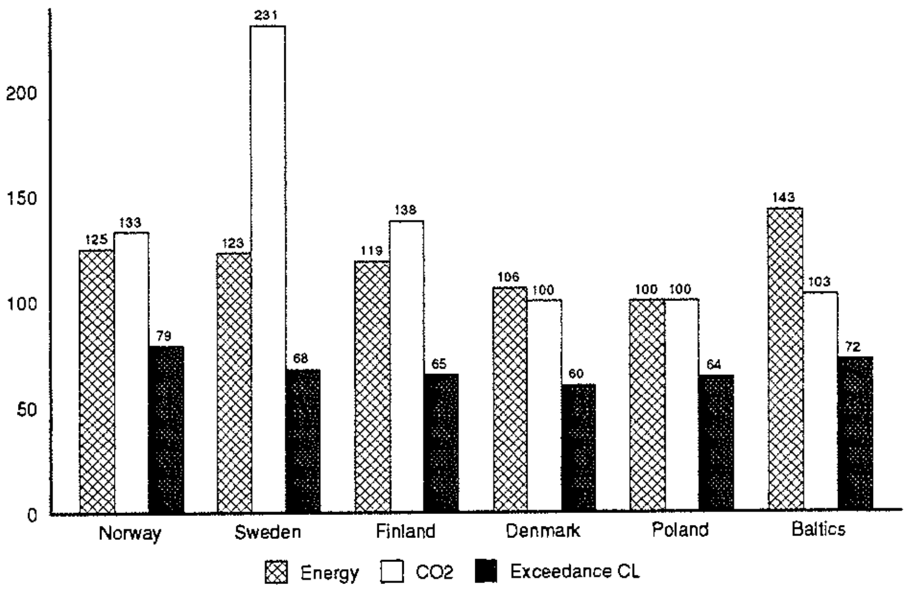

Figure 5.1 Index values of the Reference Scenario, 2010. Reference 1990 = index 100.

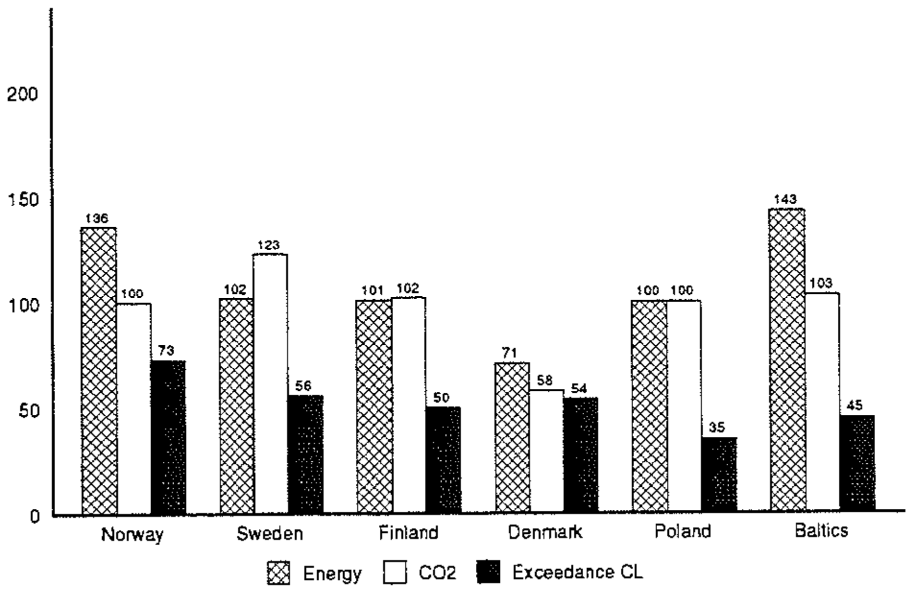

Figure 5.2 Index values of the Environment Scenario. Reference 1990 = index 100.

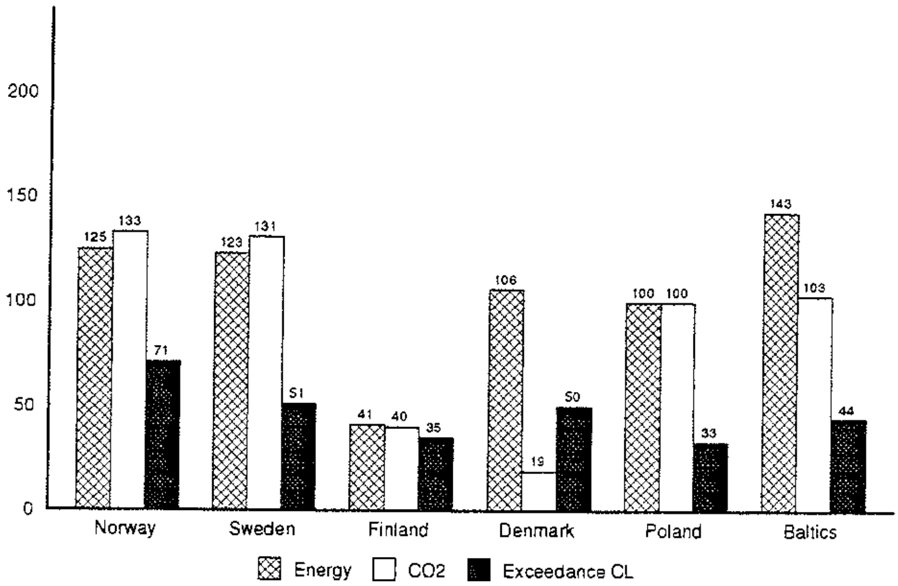

Figure 5.3 Index values of the Flue Gas Control Scenario. Reference 1990 = index 100.

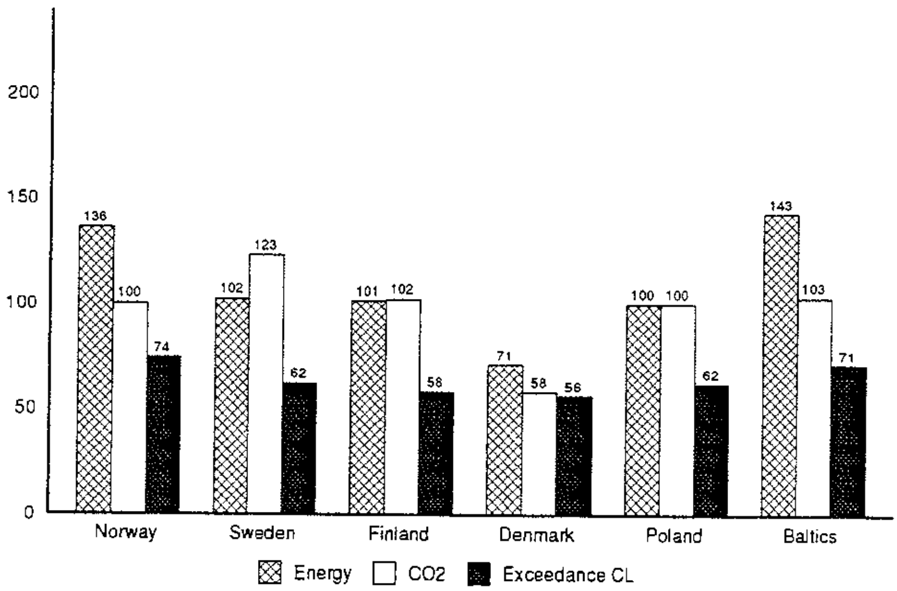

Figure 5.4 Index values of the Nordic Environment Scenario. Reference 1990 = index 100.

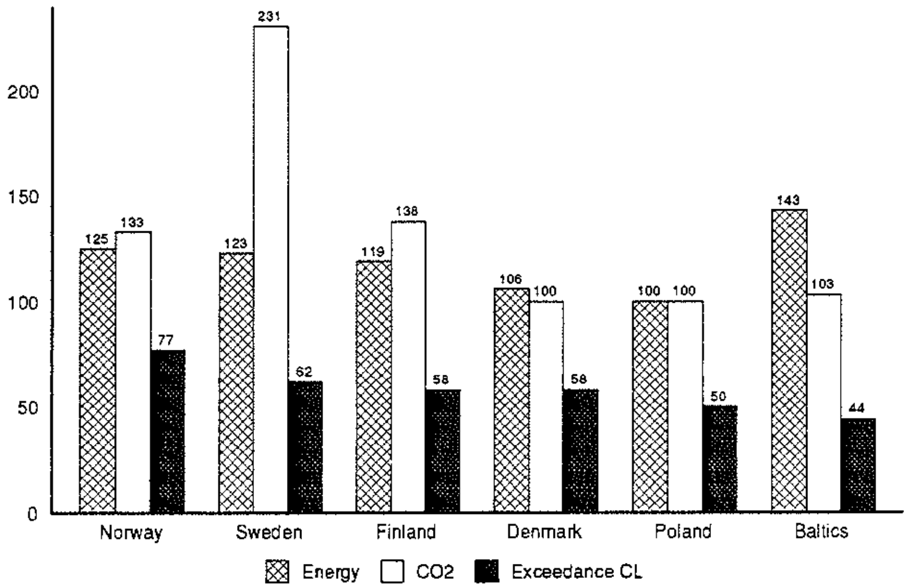

Figure 5.5 Index values of the Baltic Environment Scenario. Reference 1990 = index 100.

The Nordic and Baltic Environment scenarios can be seen as an attempt to perform and carry out coordinated and simultaneous activities in the Nordic as well as the Baltic areas. Efforts in the Nordic region, corresponding to the Nordic Environment scenario, shows that the reductions in the Baltic region are attributed mostly to reduction efforts in these countries themselves; efforts in the Nordic region have almost no effect on the Baltic region which means that in general it is a benefit only for the Nordic area itself.

There is a larger effect seen in the whole area in terms of the exceedance of critical load values when the Baltic area reduces acid emissions by the amount assumed in the Baltic Environmental scenario. The Nordic region benefits from these reductions to almost the same extent as if coordinated efforts in the whole region corresponding to the environment scenario have been carried out.

It should be mentioned that individual country initiatives scenarios also were run in terms of the acidification indicator. Their results showed that individual country initiatives in the Nordic region had no significant effect on the exceedance of critical load values of the region as such. The value of the countries themselves were a little lower and almost no benefits were observed in the neighbouring counties. Individual country initiatives in Poland or the Baltic states had a small influence on the other countries of the region. However, these influences were similar to those observed in the Baltic Environment scenario, and therefore gave no reason to draw other conclusions.

It is clear from the study that coordinated efforts in the countries can provide benefits not only within individual countries themselves, but also in the other countries of the region. It naturally most clearly focuses on the acidification indicator. The comparison between the Reference, Environment, Nordic, and Baltic Environment scenarios shows that coordinated planning provides better indicator values and hopefully lessoned environmental impacts from energy activities. However, the study also shows that the goal of lowered impacts is not necessarily reached through the application of strict regulations in the energy systems of all countries at the same time. If we focus on the relatively small regulations assumed in the Baltic Environment scenario, environmental impacts appear to be lowered by an amount similar to those given by the Environment scenario. For this reason it becomes doubtful whether these extra efforts are cost effective, and the question arises: Should more effort be put into transfer of funds and technology to the Baltic states and Poland where resources are especially in need to protect the environment?

If we consider the acidification indicator alone, lower levels of acidification can be gained by applying the desulphurization technologies to be found in the Flue Gas Control scenario.

The Baltic countries can influence their own acidification level through their own efforts, because of their present high level of acid emission.

The Nordic countries gain generally very little from the Flue Gas Control scenarios compared with the Reference scenario. The highest improvements are seen in Sweden and Finland. Further reductions in acidification levels can be achieved only through control of other sources from outside the region and through control of agricultural sources in Denmark.

6 Conclusion

This project shows that given the goals of sustainable development of the energy systems there may be significant benefits in performing coordinated environmental and energy planning in the Nordic/Baltic region. The study shows that single country initiatives are insufficient to secure a sustainable energy development since this development concept must be seen in a regional and in some cases a global perspective. In terms of environmental benefits, single country initiatives, especially in the Nordic countries give only limited gains. More coordinated energy and environmental planning must be carried out for a larger region focusing on the benefits and achievements of the region as such when putting restrictions on the energy systems developments.

It is however also obvious that the region can secure environmental benefits and economic savings by implementing actions in countries where the benefits are clearly evident in the neighbouring lands.

It should be emphasized that this does not mean that specific countries such as those in the Nordic region should relax their environmental regulations in energy use and production. Global effects to which each country contributes must be taken into account. Also, the influence of one country on another in areas of environmental protection is essential.

The study shows that with relatively simple selections and efforts, the Nordic/Baltic region could become a model of an area where coordinated planning is carried out under the concept of sustainable development.

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Appendix

The Appendix consists of two annexes:

- Annex 1: National Statistics

and

- Annex 2: The RAINS Model

The Annexes give an overview of the national statistics as represented in this report in terms of which sources have been utilized and an overview of the important aspects of the RAINS models as is utilized in the project.

Annex 1: National statistics

The following pages describe the national sources for which the national scenario and indicator values of this report have been derived. This annex shall be seen as a documentation of the calculations made in the project.

It is important to note that the figures and sources referred to here were collected and derived in the period 1990-1991. Therefore, newer and updated projections for each country's future energy use may be available now. The database has however been updated in respect to the acidification related measures - an updated version of the RAINS model was released in late 1992, which resulted in an update of the estimates of the database of this project. In respect to the Baltic states only within the last year it has been possible to gather relatively consistent data for energy systems measures. Therefore these values are the most recently gathered in 1992.

The following pages give an overview of the sources used for deriving the national estimates.

Norway

SIMEN (1989): *Studier av indistri, miljø & energi fram mot år 2000.* (in Norwegian). Statistisk Sentralbyrå, Oslo, Norway.

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Sweden

Statens energiverk (1990): *An environmentally adapted energy system. Environmentally adapted energy scenarios, Sweden 2015, Electricity and heat production, indigenous fuels.* National Energy Administration, 1990:3, Stockholm, Sweden.

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Denmark

Energiministeriet (1990): *Energy 2000.* (in Danish). København 1990.
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5) *Samfundsøkonomiske beregningsforudsætninger.* Energistyrelsen, 1990.
6) *Brundtland - scenariemodellen - BRUS.* Risø National Laboratory, Systems Analysis Department, 1990.

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Estonia

Salay, J., Fenhann, J., Jaanimägi, K, and Kristoferson, L. (1993): Energy and Environment in the Baltic States. To appear in *Annual Review of Energy and Environment*, vol 18.

Fenhann, J. (1991): *Energy and Environment in Estonia, Latvia, and Lithuania.* Risø-M-2943. Risø National Laboratory, Roskilde, Denmark.

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Latvia

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Lithuania

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Annex 2: The RAINS model

In 1983 the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria initiated the development of the RAINS model (RAINS is short for Regional Acidification INformation and Simulation). The following will give an overview of RAINS and the facilities we have used in the study. A more detailed description can be found in Alcamo et al. (1990).

The purpose of developing the RAINS model was twofold. (1) It was intended to gather existing scientific knowledge and provide an overview on causes and effects of acid deposition, as well as collect relevant statistics for characterizing and describing of these processes; and (2) to use this information in international discussions on identifying European policy strategies to diminish harmful effects of air pollution. The overall aim was to provide a tool for carrying out assessments of cost effective policy strategies for an emission protocol regulating acid emissions in Europe.

The model constitutes four more or less individual compartments each divided into one or more submodels. A schematic presentation of the model's structure can be found in Figure A2.1. The compartments are: The Energy/Emissions/Costs and Agriculture Module, the Critical Loads Assessment Module, the Environmental Impacts Module, and the Optimization Module.

Three pollutants, sulphur dioxide, SO_2, nitrogen oxides, NO_x, and ammonia, NH_3, are described in the model. It should be mentioned that RAINS can be used only for analyses of the impact of a single pollutant on the system at one time. Combined effects can be examined directly only within the Critical Loads Assessment Module.

Spatially, RAINS covers the whole of Europe (including the republics of the European part of the former USSR) in grid squares with a resolution of 150 km x 150 km for emissions and atmospheric processes, and 0.5° latitude x 1.0° longitude for the environmental impact compartment.

The temporal long-term perspective is the period 1960 to the year 2000 (2040 for the soil impact submodel) where information can be obtained at 5-year intervals. The period 1985 to 2000/2040 represents perspectives on future developments.

RAINS can be operated in two modes: either by a scenario analysis where impacts of energy consumption and emissions on the environment are analyzed (follow the arrows pointing right in Figure A2.1), or by an optimization analysis where the allocation of overall European minimal costs, as for example an environmentally specified target may be found (follow arrows pointing left in Figure A2.1).

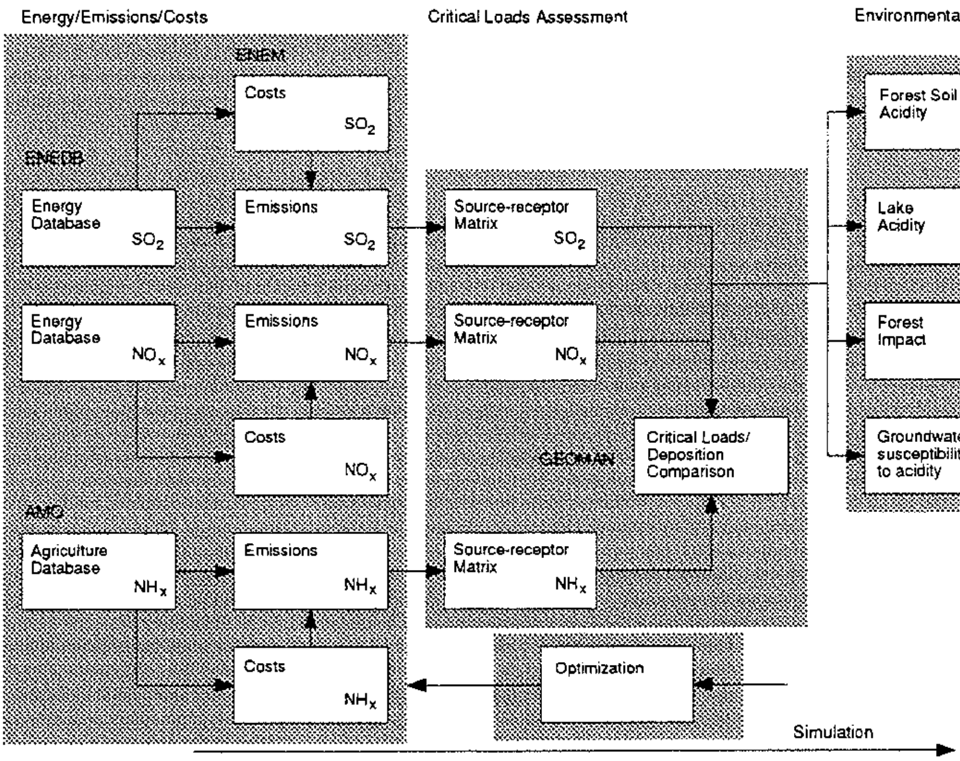

Figure A2.1 A schematic presentation of the structure of RAINS. (Source: Sørensen, 1993)

RAINS consists of several different model types. *The Energy/Emission/ Costs and Agricultural Module* is basically a database with options for making simple calculations. *The Critical Loads Assessment Module* consists of various parts, a source-receptor matrix and a Geographical Information System (GIS, called GEOMAN) allowing for a graphical display of European deposition patterns. GEOMAN provides the facility for comparison of estimated depositions with critical loads. *The Environmental Impacts Module* represents more conventionally known simulation submodels describing the effects of deposition levels on natural chemical processes. Finally, *the Optimization Module* consists of an LP-solver (Linear Programming solver) that links deposition targets to energy use and economic abatement costs.

In this study, we have used the Energy Database, and the Emission Database as well as the Critical Loads Assessment Module. Therefore, the following refers only to these parts of the model.

A common characteristic of the databases is that all statistics and projections are combined in a common database format aggregated into country, year, economic/energy-consuming sector, and fuel types used. The aggregation was made according to UN-ECE and OECD databases from where most data have been derived.

The Energy Database, ENEDB is aggregated into 6 economic sectors, and 12 fuel, and energy-using sectors. Table A2.1 lists the sectors, and fuel types and their abbreviations used in the model and here.

Table A2.1. Sectors, fuel types and abbreviations used in ENEDB.

Economic Sectors	Fuel and Energy Consumption Sectors	
Energy Conversion, CON	Brown Coal, BC	Light Fraction, LF
Power Plants, PP	Hard Coal, HC	Gas, GAS
Domestic Sector, DOM	Derived Coal, DC	Nuclear Power, NUC
Transportation, TRA	Other Solids, OS	Hydro Power, HYD
Non-Energetic Use, OTH	Heavy Fuel Oil, HF	Electricity, ELE
Industrial Sector, IND	Middle Distillates, MD	District Heat, DH

Several energy scenarios have been created by the model developers and are built into the submodel. The one used in the study was *the Official Energy Pathway (OEP)* which shows national official projections (from 1992) for energy consumption as reported from member states in the Economic Commission for Europe (ECE).

The scenarios may be the basis for user-defined scenarios in which the user can express individual, subjective viewpoints for the future development.

Within ENEDB options for abatement control are also outlined, e.g. add-on technologies or fuel switching to less-polluting types. The options and combinations with sectoral aggregation can be seen in Table A2.2. In this way the user can create his or own control scenarios in which impacts on the ecosystem can be analyzed using other submodels. This facility was utilized for East Germany (the former GDR) and the former USSR when developing the Environment and Flue Gas Control Scenarios.

The Emission Submodel is the second part of the Emission and Cost complex, ENEM. The submodel includes statistics and facilities for estimating national emissions. National statistics are expressed in so-called emission scenarios that differ from the energy scenario only in representing future expectations on national emissions without specific considerations on how this may be achieved in the energy consumption sectors.

One important scenario already implemented in RAINS is the *Current Reduction Plan (CRP) scenario* where the individual countries have expressed their official political expectations for future emission levels. This scenario may be the basis for user-defined emission scenarios where the user, i.e., can analyze impacts of reducing current emissions by a certain percentage. Also the earlier mentioned energy scenarios are represented as emission scenarios. It should be mentioned that emission scenarios based on user definitions in the Emissions Submodel do not have a corresponding energy scenario in the Energy Scenario.

Table A2.2. Pollution options for various economic sectors and fuels (source: Alcamo et al., 1990).

Sector	Fuel	Low Sulphur	Combustion Modification		Flue Gas Desulph.		Regeneration Process
			Retro	New	Retro	New	
Conversion	Hard Coal				X		
	Heavy Fuel Oil				X		X
Power Plants	Brown Coal		X	X	X	X	
	Hard Coal	X	X	X	X	X	
	Heavy Fuel Oil	X			X	X	
Domestic	Hard Coal	X					
	Coke Briquettes	X					
	Gasoil	X					
	Heavy Fuel Oil	X					
Transportation	Gasoil	X					
Industry	Hard Coal	X	X		X		X
	Coke				X		X
	Gasoil	X					
	Heavy Fuel Oil	X			X		X

Critical Loads Assessment Module

The country emissions from the Energy/Emissions/Costs and Agriculture compartment are used directly as input to the Critical Loads Assessment Module.

GEOMAN is a Geographical Information System (GIS) and constitutes the framework for the Critical Loads and Deposition Comparisons Submodel. GEOMAN is a data storage and display system for environmental information. GEOMAN has also been developed at IIASA. Its link to the RAINS model makes it possible to view graphically the European deposition patterns resulting from various scenarios in gridded maps showing either a numerical value or displayed as a colour that represents a range.

The submodel contains the database on critical loads (see Annex 1 for details) compiled by the Coordination Center of Effects, RIVM, Bilthoven, the Netherlands. This database contains for each EMEP grid cell a cumulative frequency distribution of the Critical Loads of sulphur and of total acidity. In this way the results of an energy strategy can be assessed by comparing the deposition values with the officially accepted levels which form the goals for emission reductions in Europe.

The Critical Loads frequency distributions are expressed in terms of percentiles. The user can personally select the percentile to be used as a basis for making the comparisons. We decided on the 5 percentile.

This facility was used to calculate values of the indicators of acidification throughout the region.

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1993:639	Energipolitik i plan och verkelighet *- i de nordiske länderna*
1993:640	Perspectives of Regional Coordinated Energy and Environmental Planning

Perspectives of Regional Coordinated Energy and Environmental Planning

Nordic cooperation on energy

The Nordic Council of Ministers wishes to promote Nordic cooperation on energy e.g. by coordinating energy supply and consumption in accordance with sustainable developments, and by maintaining secure energy supply on a high level. Nordic cooperation on energy policy will concentrate on several main areas, such as a joint Nordic electricity market, a joint Nordic gas market, increasing efficiency in the energy sector, use of cleaner energy sources, Nordic cooperation on energy research and international cooperation.

The Nordic Council of Ministers

was established in 1971. It submits proposals on co-operation between the governments of the five Nordic countries to the Nordic Council, implements the Council's recommendations and reports on results, while directing the work carried out in the targeted areas. The Prime Ministers of the five Nordic countries assume overall responsibility for the co-operation measures, which are co-ordinated by the ministers for co-operation and the Nordic Co-operation Committee. The composition of the Council of Ministers varies, depending on the nature of the issue to be treated.

The Nordic Council

was formed in 1952 to promote co-operation between the parliaments and governments of Denmark, Iceland, Norway and Sweden. Finland joined in 1955. At the sessions held by the Council, representatives from the Faroe Islands and Greenland form part of the Danish delegation, while Åland is represented on the Finnish delegation. The Council consists of 87 elected members - all of whom are members of parliament. The Nordic Council takes initiatives, acts in a consultative capacity and monitors co-operation measures. The Council operates via its institutions: the Plenary Assembly, the Presidium and standing committees.

The Nordic Council of Ministers

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